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Oil impregnation of Douglas fir using a pressure reduction and an oil-water treatment

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OIL IMPREGNATION OF DOUGLAS FIR USING A PRESSURE REDUCTION AND AN OIL-WATER TREATMENT

by

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ABSTRACT

Two methods of injecting a 5 per cent solution of pentachlorophenol into Douglas fir poles were developed, to improve the depth of penetration and to produce an oil-free surface, through laboratory experiments, which used one and three foot long pole sections, and were evaluated by means of commercial scale tests.

During the experiments a theory of liquid flow through wood was evolved: that air is trapped within the treated wood and that the degree of compression of this trapped air controls the volume of oil that may be injected and its distribution. From this theory the general effects of time, temperature, pressure, retention, and other treating variables on penetration and the accumulation of an oil layer on the pole surface can be predicted.

In both methods of treatment the wood is surrounded with oil at atmospheric pressure and the pressure is increased to 150 psi to force the oil into the wood. In the "oil-water" treatment, water was injected after the oil period, then the poles were steamed and a vacuum applied to vaporize the injected water. The laboratory experiments showed that the penetration was improved if the oil to water change was made at the oil treating pressure,

and if the water period was extended to 6 hours. Raising the water pressure increased the penetration, but lowering the pressure produced a less oily surface. In the "pressure reduction" treatment a high initial oil pressure was slowly reduced to atmospheric, and the wood was then given a steaming and a vacuum cycle. This treatment produced deep penetrations with low oil retentions.

To evaluate these experimentally developed treatments, five charges were treated in a commercial plant: one by the conventional method to act as a control; three by the oil-water method; and one by the pressure reduction method. The pressure reduction charge had a retention of about 5 lb per cu ft of pole and the other retentions ranged from 6 to 7 lb per cu ft of pole. The penetrations were greater in the non-incised and incised areas of the oil-water charges than in the control, and greater in the incised but lower in the non-incised areas of the pressure reduction charge than in the control. All treatments produced oil-free pole surfaces. The increase of penetration due to incising was much greater in the oil-water and pressure reduction charges than in the control, and the pentachlorophenol concentrations in the oil-water and the pressure reduction charges were higher in the incised areas than in the non-incised, while the reverse was true in the control.

The oil-water treatment appears preferable to the pressure reduction treatment, but, because the data from the latter on a commercial scale were insufficient, no valid comparison can be made. It is believed that the improvements resulting from the oil-water and pressure reduction treatments warrant their slight additional cost, but this cannot be definitely concluded until the service lives of the poles are known.

Continued commercial scale testing of the oil-water and pressure reduction treatments on a semi-production basis is recommended.

INTRODUCTION

Because preservative treatment prolongs the service life of wood and allows the utilization of low grades and assorted species of wood, it has become a standard method of increasing the effective supply of this national resource.

In this country, the wood preservation industry began to develop about the turn of the century, and by 1949 there were 262 plants treating 290 million cubic feet of wood and consuming 205 million gallons of oil preservatives each year. Railroad ties were the first objects of preservative treatment, but today poles represent about one third of the volume of all treated wood.

In the past, electric power line poles were of western cedar which, due to its inherent resistance to decay, gave long service with little preservative treatment. As the supply of western cedar diminished, utility companies in the Chicago area started using Douglas fir which contains a deep band of easily decayed sapwood that must be penetrated by preservatives if the pole is to give long service. Considering that it costs from $100 to $1,000 to replace an electric power line pole (although the cost of the treated pole is only about $50) increasing its service life 10 to 30 years by preservative treatment becomes an economic necessity.

When, by present commercial pressure treatment, enough oil preservative is injected to penetrate the band of sapwood in Douglas fir, some of the oil flows back onto the surface of the pole after treatment. A pole with a wet surface is particularly objectionable to linemen and others coming in physical contact with it. However, if an oil-free surface is produced by injecting less oil into the pole, the resulting shallow sapwood penetration considerably shortens the expected life of the pole.

Thus, the problem is to develop a method of treatment that not only obtains deep sapwood penetration in Douglas fir poles, but also leaves the surface free of oil throughout the life of the pole.

REVIEW OF THE LITERATURE

Background Information

The following background information on the requirements for proper treatment, the structure of wood, and the types of commercial treatment is given to prepare the reader for the discussions that follow.

Requirements for proper treatment

The requirements for properly treated wood are that the physical properties other than density should not be materially altered, that the treatment should keep wood destroying insects and fungi inactive, and that the appearance and surface of the wood should not be objectionable. Usual treating conditions and materials injected into the wood do not appreciably change its electrical conductivity.

To be active, the wood destroying fungi and insects must have proper temperature, sufficient moisture, sufficient air, and a food supply. When wood is in outdoor service there is little or no control over moisture, temperature, and air, and so the food supply, the wood itself, must be poisoned. Injecting the wood with a preservative will accomplish this if a sufficient depth of penetration is obtained and a lethal concentration is retained.

Of the two types of poisons or preservatives, the oil soluble preservatives (i.e., creosote or organic solids such as oil solutions of pentachlorophenol) are preferred for out-door service, because the water soluble preservatives tend to leach out of the wood. Wood treated with oil preservatives sometimes excretes oil or "bleeds," leaving an objectionable oily residue on the surface.

Wood structure

The soft woods, or conifers, consist essentially of wood tracheids and wood rays. This is shown in Figure 1.

The wood tracheids, arranged in definite radial rows, are hollow, axially elongated, imperforate cells of a square or rectangular cross section, about 100 times as long as they are wide. In woods such as southern yellow pine and Douglas fir the cells formed in the earlier part of the yearly growing season have thin walls and are known as spring wood, while those grown later in the season have thick walls with relatively smaller cavities and are known as summer wood.

Small openings between the wood tracheids, called bordered pit pairs, are circular permeable membranes with a thickened section in the middle, called a torus. The secondary cell walls overhang the membrane and torus so

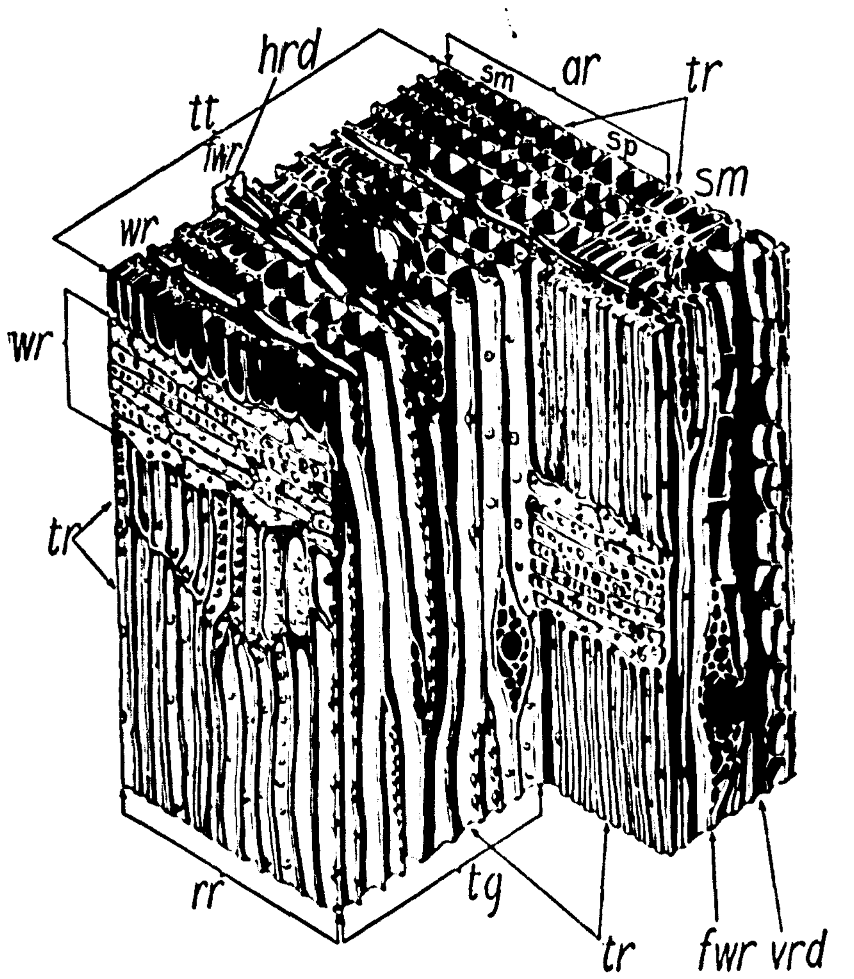

Figure 1. Magnified drawing of the structure of a softwood:* tt, end surface; tg, tangential surface; rr, radial surface; tr, tracheids; wr, wood ray; fwr, fusiform wood ray; vrd, vertical resin duct; hrd, horizontal resin duct; sp, springwood; sm, summerwood; ar, annual ring.

*Stamm, A. J. Passage of liquids, vapors and dissolved materials through softwoods. U.S. Dept. Agr. Bull 929. 1946. p. 3.

that, if the torus is displaced, it rests against the cell wall. This is called pit aspiration. It is reported that the aspirated pits act as a valve and do not permit fluid flow. The bordered pit pairs occur mainly at the ends of the wood tracheids; they also occur on the sides of the cells, the greater percentage occurring on the radial side.

Wood rays are ribbon-like aggregations of relatively small cells extending radially in the wood. They consist mainly of parenchyma cells and have simple pits, devoid of a torus and cell wall overhang. The membranes of the simple pits have never been shown to contain perforations, and it is generally believed that the rays do not assist fluid flow.

Resin ducts are long, narrow openings in the wood and when radial are called fusiform rays. They are surrounded by parenchyma cells; which, although they contain resinous matter, assist the flow of fluid.

Sapwood, the outer part of the tree, is physiologically active. The inner part, heartwood, acts only mechanically. As the tree continues to grow, the new cells at the surface become sapwood and the oldest sapwood cells become heartwood. The sapwood in Douglas fir, while difficult to treat, is more easily treated than the heartwood, which is more resistant to decay. Due to the resin deposited within its cells, the heartwood is darker in color than the sapwood.

Types of commercial treatment

There are three general types of treatments in which pressures above atmospheric are used to force a liquid preservative into the wood.

In the Lowry process the wood is placed in a cylinder, the preservative is introduced, and then the pressure is applied. After a sufficient amount of preservative is absorbed by the wood, the pressure is relieved, the liquid pumped out, and a vacuum applied to recover some of the preservative.

The two other high pressure treatments are similar to the Lowry treatment, differing only in that the pressure is applied to the wood before introducing the liquid.

In the Rueping, or empty-cell process, air pressure is applied to the wood before introduction of the preservative, and after the preservative is introduced, the pressure is increased.

In the Bethell, or full-cell process, a vacuum is applied to the wood, then the preservative is pumped in, and the pressure on the preservative is raised.

In addition to the vacuum applied after the pressure period, steaming of the wood and expansion baths (in which the wood is heated in oil at atmospheric pressure) are sometimes used not only to increase the liquid recovery during the vacuum, but also to assist in obtaining non-bleeding wood.

Factors Affecting Penetration and Retention

Though the many factors that affect the penetration and retention, i.e., wood, permeability, fluid, pressure, and viscosity and temperature, are often interrelated, they are best discussed individually.

Wood

The effect of the wood on penetration and retention is a function of its structure, moisture content, and the conditions imposed upon it before treatment.

Structure. The average fiber length of Douglas fir is 3.8 mm, but, due to overlapping, the effective length is about three fourths of the average length. The average number of fibers in the radial and tangential direction is 300 per cm, and their average radius (assuming they are circular) is 15.2×10^{-4} cm. The effective fractional cross section of pit membrane pores in the tangential direction is 0.00052, and the pit membrane is estimated to be 10^{-4} cm thick (42). The pit membrane pore size varies with the direction, wood, and other factors, ranging from 10 to 108 millimicrons (40), with an average value of 28.2 millimicrons in the tangential and radial directions (42).

Though the pit membranes have holes (3) they are not always effective for fluid flow, since aspiration* may occur. Aspiration is not caused by fluid pressure (26) but appears to be a drying phenomenon, due either to the shrinkage of the wood or the surface tension of the water in the pit. The degree of aspiration increases gradually as the wood dries, as long as the moisture content is above the fiber saturation point. It then increases rapidly as the fiber saturation point is reached (34). Below the fiber saturation point, the moisture content has no effect on aspiration, and resoaking does not relieve aspiration (34). The proportion of unaspirated pits increases with wall thickness, average counts of five woods ranging from 0.5 to 6.3 unaspirated pits per fiber in the spring wood and from 2 to 11 unaspirated in the summer wood (34). The structure, size, and degree of aspiration of the pits are the same from the pith to the outer heartwood (13, 34).

British grown Douglas fir showed an average of 92 spring wood pits and eight summer wood pits per fiber. Of these, an average of 0.9 pits per fiber (one per cent of the total) were unaspirated in the spring wood, and 2.0 pits per fiber (25 per cent of the total) were unaspirated in the summer wood (34).

The pit closure in American Douglas fir summer wood is

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*See page 4.

less extensive than that in the spring wood (18, 19, 30). Mountain-type Douglas fir has a considerable number of aspirated pits in the green summer wood, both heart and sapwood, unlike coast-type Douglas fir (18). The air dry mountain-type Douglas fir has a greater amount of aspiration in both spring and summer wood, and oven drying causes aspiration in both spring and summer wood (18).

Moisture content. The moisture content, as was pointed out above, affects the degree of pit aspiration. The rate of longitudinal water flow through green jack pine is from four to five times that through the seasoned wood (26); and white spruce shows the same tendency (44). The flow rate of benzene and nitrobenzene is reported to decrease as the moisture content below the fiber saturation point increases (8).

Erickson and co-workers (13) found that seasoning did not affect the rate of longitudinal flow in Douglas fir. However, the size of samples used and method of seasoning did not represent that found in industry. His work tended to show how wood can be seasoned without causing pit aspiration, by slowly lowering the humidity while keeping the temperature constant. The treating industry generally considers that the method of seasoning affects the ease of treatment.

The moisture content and specific gravity affect the porosity of wood; the void (air) volume increases as the moisture content decreases. Then more oil would be needed to obtain the same penetration if the void volume of the wood was increased, because the volume of each cavity would be greater.

Pretreating conditioning. In the most general method of pretreating wood, incising, knives are thrust into the wood making incisions up to three fourths of an inch deep. The knives are designed to split rather than cut the wood, causing little reduction in its strength. This incising, generally used for the refractory woods, allows additional retentions and penetrations (24). In sawed Douglas fir beams, the non-incised portion absorbed 9.48 lb of creosote per cu ft of wood compared to the 13.60 lb retention in the incised portion. The increase in the depth of penetration due to incising is not greater, and sometimes less, than the depth of the incisions.

Steaming wood before the oil impregnation period is another pretreating condition which generally assists treatment. An alternative of this consists of preheating the wood in the treating oil at atmospheric pressure. Oil additives have been used to increase treatability, but are not generally accepted.

Permeability

Permeability is a function of the wood, moisture content, direction of flow, pressure, fluid flowing, and time of flow.

Direction of flow. Wood structure permits fluid flow more rapidly in a longitudinal direction (26, 44) and end penetration on coast Douglas fir may be 15 to 22 times the side penetration (31).

Spring and summer wood. Permeabilities of spring and summer wood differ. Generally, summer wood is more permeable (24, 36, 46), however, the springwood in two types of southern pine (seasoned and unseasoned) (13), redwood, yew, and tamarack (46) is more permeable than the summer wood. Water soluble dye solution, forced into red spruce sapwood, stained the spring wood more than the summer wood, whereas in the heartwood, the reverse was found (37). The summer wood of loblolly pine absorbed 80 per cent more creosote than the spring wood (46), and the summer wood of freshly treated southern pine generally absorbed less creosote than the spring wood (9).

Time. Permeability data are ordinarily obtained from liquid flow through wood blocks saturated with the liquid and therefore do not represent the impregnation process during actual treatment, where the boundary conditions vary and a decreasing amount of liquid enters the wood. Actually, steady state flow does not occur when liquid is forced through saturated blocks because the flow rate decreases with time (8). The flow rate was first thought to decrease to a constant value (14), but later was shown to reduce almost logarithmically with time (1). Postulated causes of the decreasing flow rate are: swelling of the woody structure, plugging of the pit membrane pores by particles, air in the wood, liquid which would tend to plug the pores by means of the liquid-air surface tension, and electrokinetic effects. Anderson and co-workers (1) showed that the above theories partially explained, but were not the primary reasons for the decreasing flow. He suggested that the wood fibers in the pit membrane move so as to produce a greater resistance to flow. The decreasing flow rate is magnified by increasing polarity of the liquid (8).

Pressure. The steady state flow rate is dependent only on the pressure differential, not on the static pressure, and increases directly with or more rapidly than the pressure differential (6, 43). The non-linear flow rate increases with pressure were thought to be caused by the bulging of the pit membranes (26), thus increasing the pit membrane pore size (10), which would appear to be true as steaming wood (which makes it more pliable) increases the flow rate (21). The above theory has been shown to be mathematically unsound, and an alternate theory proposed that lateral movement of the fibers increases the area of the large capillaries at the expense of the smaller ones (1).

Pits. The pit membrane pores are so small that they account for the major resistance to flow. The resistance of the cell walls to radial and tangential flow is considered negligible and the type of flow has been shown to be laminar (15, 39, 40, 42). The impact resistance of the pit membrane pores to the flowing liquid can be computed from Couette's modification of Poiseuille's equation, and in the case of heartwood is negligible (41).

The number of unaspirated pits and penetration is interrelated (18, 19); the pit aspiration is not affected by the pressure (6). While the flow appears to occur within the tracheids (37), the rays may assist flow through localized zones of wood tracheids and from summer wood band to summer wood band (4). Hartman (20) found the susceptibility of wood to impregnation to vary inversely with the total cross sectional area of the resin ducts per unit surface area, and the speed of penetration to vary directly with the average tracheid diameter. Bailey, Teesdale, and MacLean found little or no penetration into wood rays or parenchyma cells.

Two phase flow. The presence of gas in the wood reduces the liquid flow rate (1, 12, 35), and water flows easily through wet wood which resists gas flow at the same pressure differential (44). As the flow path lengthens, resistance to flow increases more than linearly. This is explained by the "Jamin's tube" effect, in which capillary alternate gas-liquid menisci transmit less pressure than they receive, due to the menisci adjustment (6).

Fluid

Erickson and co-workers (13) concluded from MacLean's work (28) that the fluid composition significantly affects fluid flow. Oils of the same viscosity have different flow rates (8, 17, 23). The flow rate of normal primary alcohols forced through a cellulose pulp membrane increases with the number of carbon atoms more than would be expected from a change in viscosity. Flow rates generally decrease as the liquid polarity increases (6, 8).

The capillary penetration into wood blocks is greatest with water, alcohol, diaxon, carbitol, ethylene glycol. diethylene glycol, propylene glycol, and glycerine, in decreasing order; the penetration rate increases as the viscosity decreases (25).

Pressure

Three types of pressures or forces, capillary and surface tension, internal air pressure, and the external oil pressure, affect the flow of liquid.

Capillary and surface tension forces. Although various grades of creosote treat differently, no correlation has been shown between surface tension, interfacial tension, and the distilling range of creosote (16, 17), nor has any relation between penetration qualities and interfacial or surface tension been found (22). Surface tension is apparently a function of the moisture content, because the pressure necessary to overcome the surface tension of benzene in wood increases as the moisture content of the wood increases (8).

Initial air pressure. Initial air pressure affects creosote retention but not penetration (7, 45). Teesdale (45) found that maximum initial absorption depends not only on the initial air pressure, but also on the wood treated. Initial absorption is greatest at 75 psi for hard maple, hemlock, and red oak, and with a vacuum for loblolly pine. He found that the initial pressure did not retard the rate of impregnation in oak and maple, while it did so in hemlock. The net retention decreases as the initial air pressure increases, and the use of vacuum may or may not, depending on the wood, materially increase the recovery.

Oil pressure. Increasing the pressure on the impregnating liquid increases penetration and retention rates (27, 29, 30, 33), and large timbers withstand more pressure than smaller ones before collapsing (27).

The flow rate increases linearly or more than linearly, depending on the wood, with increasing pressure differentials (6, 8, 26, 44); and not as the square root of the pressure differential as theoretically determined by Hawley (21). Anderson and co-workers (1) determined the relationship:

$$R_2/R_1 = (P_2/P_1)^n$$

where R is the flow rate at the corresponding pressure differential P. The value of n remained fairly constant for non-resinous woods, but decreased for other woods when the pressure differential increased; an average value of n is 2.0.

<u>Viscosity and temperature</u>

Viscosity is a function of temperature but each individually affects penetration and bleeding.

<u>Viscosity</u>. Hawley (21) theoretically determined that the penetration, retention, and flow rate varied inversely with the square root of the absolute viscosity. MacLean (27, 28, 29) varied the viscosity by blending oils, and concluded that viscosity was the primary factor affecting retention and penetration; but Erickson and co-workers (13) concluded from MacLean's work that this was not necessarily true.

<u>Temperature</u>. Increased temperatures of zinc chloride solutions (27, 30, 32, 33), creosote, and creosote-oil

solutions (5, 28, 29, 30, 32, 33, 42) increased penetration and retention, even when the viscosity was held constant (28, 29, 33). The flow rate of water increased with an increase in temperature more than can be predicted by the decrease in viscosity and the flow rate is permanently increased if the temperature is temporarily raised above 160°F (26, 44). If the temperature rises above 260°F, the flow rate increases with time (6).

Factors Affecting Bleeding

Bleeding, a flow of oil from the wood interior to the surface, results in an objectionable layer of oil on the wood surface. The most important factors causing bleeding are considered to be the type of oil used, the treating schedule, and the wood (2, 24, 33, 48, 50).

Temperature

Heat is considered partially responsible for bleeding (24) as temperatures up to 168°F have been recorded on the hot side of a standing pole (11), and generally the hot side is from 12 to 24°F hotter than the shaded side (50). The bleeding on the hot side stops if the sun is obscured (49), and no bleeding has been observed on the shaded sides of poles. While bleeding is heaviest in the first year, it may appear periodically for several years thereafter (24).

Oil

The bleeding of straight coal tar creosotes is less objectionable than mixtures, and that of the lower boiling creosotes less objectionable than those with higher residues (24, 50). This may be due to the relative rates of evaporation (9, 33), for if the evaporation rate of oil is sufficient, no oil will accumulate on the surface. The bleeding of aromatic oils is less objectionable than naphthenic or paraffinic oils of comparable viscosities, and above a critical viscosity of aromatic oils (over 200 S.U.S. at 100°F) bleeding apparently does not occur (38). When vegetable phosphates are added to creosote the bleeding is reportedly reduced (48).

Wood

The more refractory the wood, the more severely it bleeds (24). Hunt and Garratt reason that since the summer wood oil concentration is higher than the spring wood concentration, wood high in summer wood would bleed more than that low in summer wood.

Treating schedule

Full cell treatments bled more than empty cell treatments, even when higher retentions were obtained in the empty cell treatments (50). In southern pine poles minimum bleeding occurred with the Lowry treatment, with an oil temperature of 160°F (in contrast to 180 or 200°F), and with lower retentions (11). A steaming and vacuum cycle used before or after impregnation reduced bleeding, and, if the vacuum period after the treatment was prolonged from 30 to 60 minutes, bleeding increased (11). High retentions near the surface apparently increase bleeding (24).

LABORATORY EXPERIMENTS

This section is divided into the plan of investigation, equipment, supplies, procedure, results, and discussion of results.

Plan of Investigation

At the time the experiments were commenced, very little reliable information was known upon which to formulate a theory of liquid flow through wood, or otherwise design experiments. As commercially conducted, wood preservation was an art rather than a science. The observations reported in the literature were often not in agreement, or not complete, or not applicable to the development of a theory of flow. Only the effect of a few treating conditions could be predicted and these in only a very general way.

Therefore, it was necessary to base the design of the experiments on assumptions derived from an analysis of the most reliable information that could be obtained. Evaluation of the experimental results formed the basis of new assumptions. During the experiments a concrete theory of fluid flow through wood was developed and this theory was applied to the design of experiments whenever possible. However, it was impossible to determine the relative effect of final conditioning, vacuum, steaming, and expansion bath, by means other than experimentation.

Previous experiments had shown that deep penetration and dry poles could not be obtained by the standard methods of treatment without long steaming periods, which were considered detrimental to Douglas fir wood and prohibited by the standards of American Wood-Preservers' Association.* Therefore, two alternate hypotheses were possible, one that steady-state flow occurred and the other than unsteady-state flow occurred. From these assumptions, two methods of treatment were developed.

Oil-water treatments were based on the assumption that steady-state flow occurred. In this type of flow injection of water after the oil would push the oil farther into the pole and increase the penetration. If the water was removed to leave a void space near the wood surface, then any oil moving towards the surface after the treatment would fill the void volume rather than flow onto and wet the surface.

Pressure reduction treatments were based on the unsteady-state flow theory which predicts that penetration

*This was true when the work was started, but recently the Association has considered an amendment to permit extension of the steaming period for Douglas fir poles. It is probable that this action is due more to a desire to produce non-bleeding poles than a consideration of the effects of steaming on the strength of the wood.

will be increased and bleeding reduced if a low treating pressure is used. Use of a low treating pressure will require uneconomically long times. So the experiments were based on the principle that a high initial pressure is used to obtain, relatively quickly, the retention and then the pressure is slowly reduced so as to end the treatment with a low treating pressure.

Since the problem was to develop treating schedules applicable to commercial use, all of the data needed for complete verification of the theory were not obtained.

Equipment

The treating unit consisted of five major parts:

1. Treating cylinder. This was made from a standard gauge 12 inch iron pipe 5 feet long and was placed vertically. The bottom was closed with a 5/8 inch steel plate reinforced with a 3 by 3 by 3/4 inch angle iron. A lid, placed at the top, was bolted to a flange. Both flange and lid were made from 5/8 inch thick steel plate and the lid was reinforced with a 3 by 3 by 3/4 inch angle iron.

2. Standpipe. This was made from a standard gauge 5 inch pipe 4 feet long, placed vertically with the top and bottom closed. A 4-foot long sight glass was used to measure

the liquid in the standpipe and was calibrated in pounds of oil.

3. Pump. A $3\frac{1}{2}$ gpm capacity, reversible flow, solid displacement rotary pump with $\frac{1}{2}$ inch ports was used. It was driven at 1725 rpm by a 1/3 HP electric motor equipped with a reversing switch to permit pumping in either direction.

4. Heat exchanger. This consisted of a 3/8 inch standard iron pipe through which the treating liquid flowed, surrounded by a 3/4 inch standard iron pipe and had a heated length of 4 feet. Steam, water, or a mixture of steam and water was introduced into the annular space between the two pipes to heat or cool the treating liquid.

5. Rueping tank. This was made from a standard gauge 12 inch iron pipe 7 feet long and was placed vertically. The bottom and top were closed with 5/8 inch steel plates which were reinforced in a manner similar to the bottom and lid of the treating cylinder.

The treating unit was designed for a maximum working pressure of 250 psi. The treating tank, Rueping tank, heat exchanger, and piping were covered with 85 per cent magnesia insulation.

The temperature of the treating liquid was regulated by a solenoid valve on the steam line to the heat exchanger, the valve was controlled by a recording thermometer with the sensitive element in the treating cylinder. Pressure was developed by introducing compressed air into the top of the treating cylinder and was regulated by means of a manually controlled pressure reducing valve. Thermometers, pressure gauges, and steam and vacuum lines were also installed.

A schematic drawing of the treating unit is shown in Figure 2a and Figure 2b is a photograph of the equipment. In operation the wood and oil were placed in the treating cylinder and half of the standpipe was filled with oil. The oil was pumped from the standpipe through the heat exchanger and into the bottom of the treating cylinder. The liquid flowed to the top of the cylinder and then overflowed back into the standpipe; the oil was continuously circulated during the treatment. As a constant volume of oil was maintained in the treating cylinder, any liquid entering the wood resulted in a drop in level in the standpipe.

Supplies

The supplies consisted of Douglas fir wood and a treating solution of five per cent by weight of pentachlorophenol in a light petroleum oil.

Wood

Both mountain-type and coast-type Douglas fir was used. At first 3-foot sections were cut from unbored anchor logs

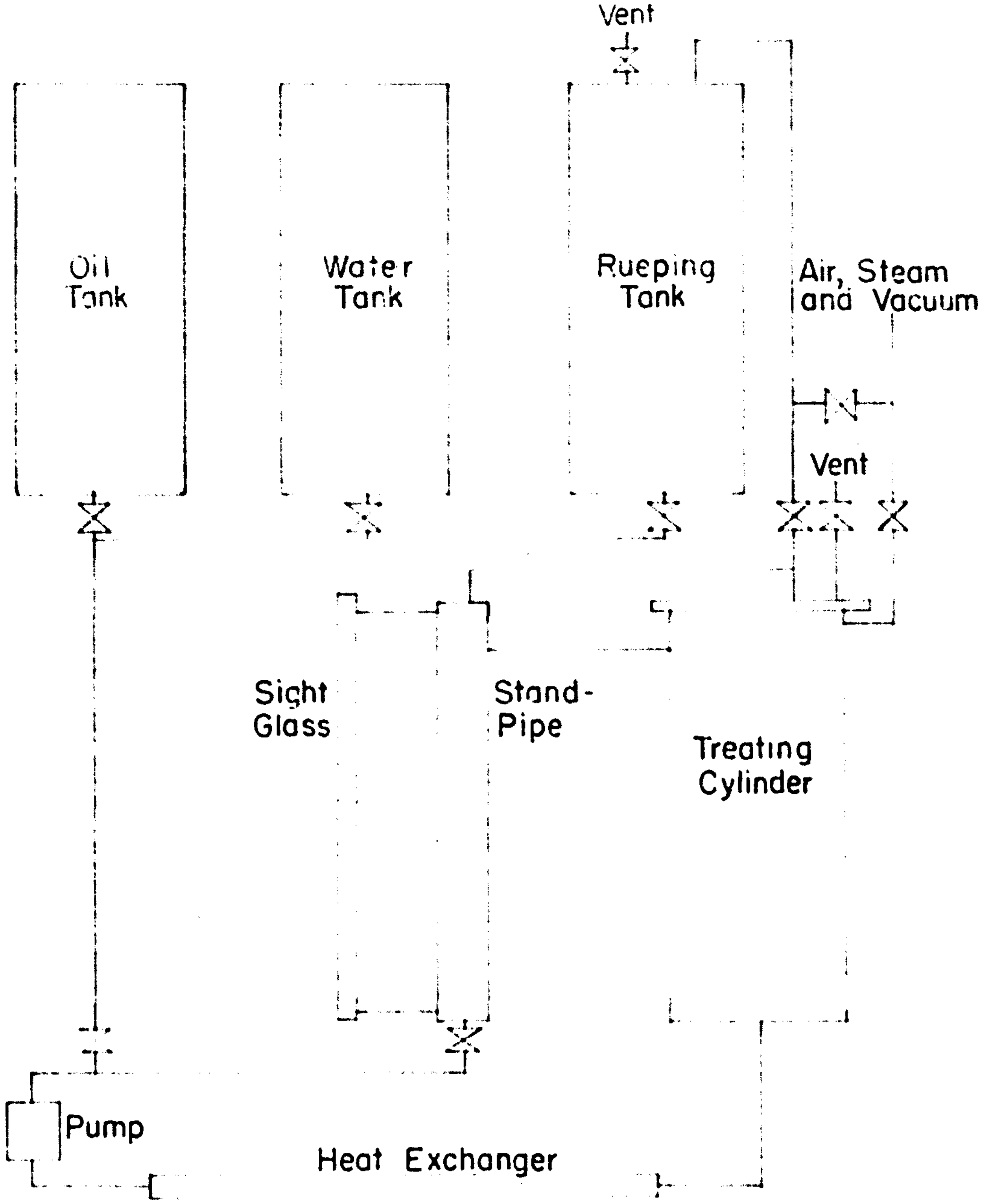

Figure 2a. **Schematic drawing of the treating equipment**

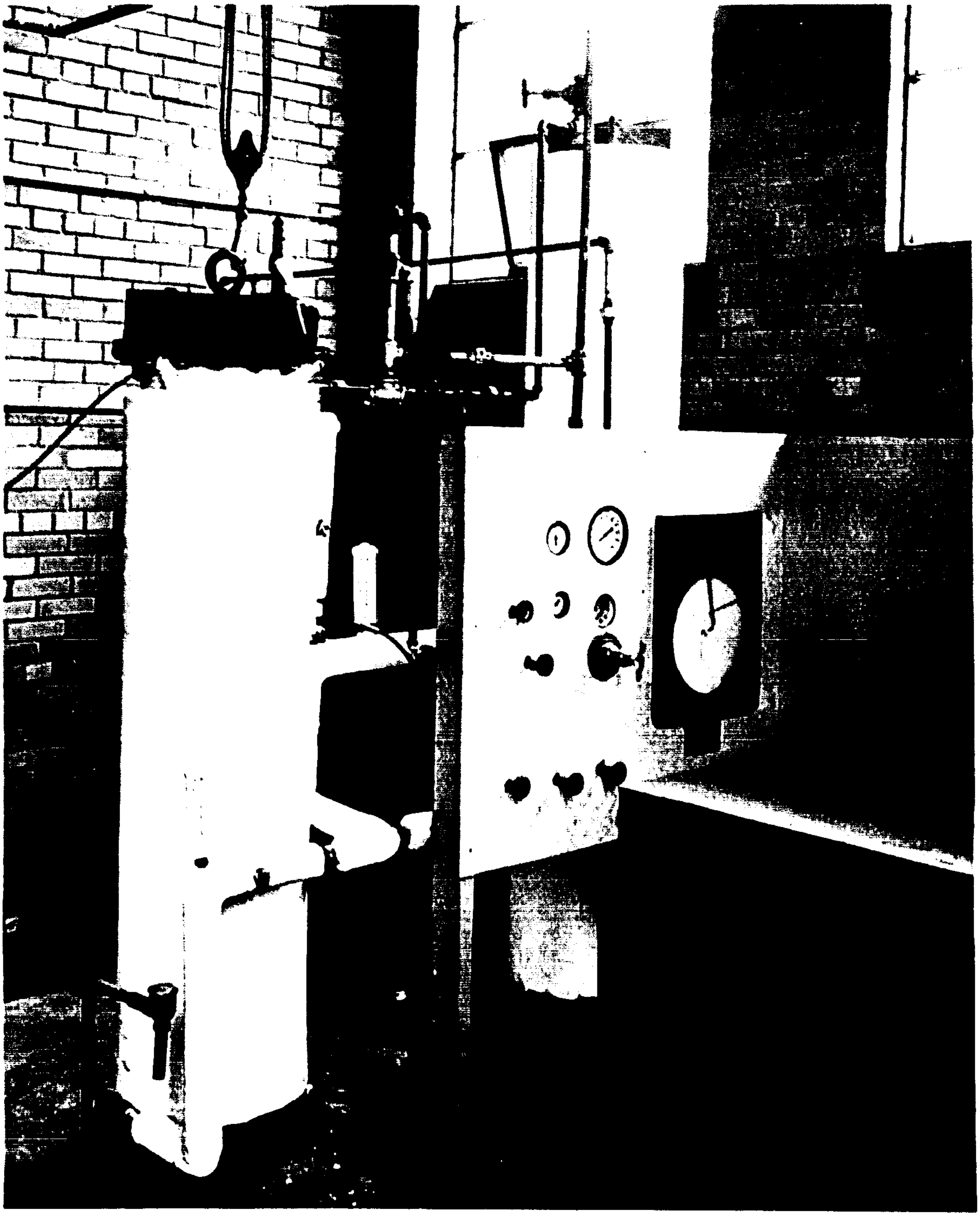

Figure 2b. Laboratory treating equipment

5 feet long; these sections (all coast type Douglas fir) are designated by numbers. Later 30-foot poles were cut into 1- or 3-foot sections and designated by two sets of numbers separated by a hyphen; the first represents the pole number, the second the number of the section cut from the pole. Pole No. 4 was mountain-type Douglas fir and the remainder coast-type Douglas fir.

All sections were air dried, contained well developed seasoning checks, and had a minimum number of large knots. Except for a few cases, the sections were selected with sap-wood depths greater than 1¼ inches.

Oil preservative

The preservative used was a five per cent by weight solution of pentachlorophenol in an aromatic petroleum cracking oil which had the following specifications: specific gravity 26° A.P.I., aniline point 115, viscosity 35-40 Saybolt at 100°F, boiling range 485-700°F. The pentachlorophenol solution was supplied by the Franklin Park plant of the Joslyn Manufacturing and Supply Company.

Procedure

The three phases in the experimental procedure were: the preparation of the wood samples; operation of the treating equipment; and collection of data.

Preparation of wood

The pole sections were coated on each end to prevent end penetration. The coating (the procedure is given in Appendix A), when properly applied, limited the end penetration to about 1 inch. Any large knots present in the sections were coated with Tygon paint to retard oil flow.

Operation of treating unit

In all treatments the oil was introduced into the treating cylinder at atmospheric pressure. About 15 to 30 minutes were required after the pole was surrounded by oil to bolt on the lid and regulate the oil temperature to the desired value. The pressure was increased from atmospheric to the maximum pressure (usually 150 psi) in less than 2 minutes.

In the oil-water treatments about ½ hour was required to remove the oil and replace it with water. The Rueping tank was used when the water was introduced under pressure.

About 10 minutes were required to vent the cylinder of air and bring the steam pressure up to 10 psi, and about 2 minutes were required to reach a vacuum of 22 inches of mercury.

Collection of data

Data on the physical properties of the pole sections, oil retention, penetration, oil distribution, and bleeding were obtained.

Pole. The average diameter and sapwood depth at each end of the section, the length, and weight of the section after coating the ends were measured, and the moisture content was determined by oven drying at $105^{\circ}C$ for 24 hr. A sharp sapwood-heartwood line was obtained by painting the cross section with water glass.

Retention. The gross oil retention was determined from the sight glass readings and the net retention from the weight gain of the section. When the water in the oil-water treatment was introduced at pressures above atmospheric, the net oil retention was assumed equal to the gross retention, and the net water retention was assumed to be the difference between the gross oil retention and the total weight gain of the section. When the water was introduced at atmospheric pressure, the section was weighed between the oil and water parts of the treatment and the net water retention was calculated from the weight gain after the oil impregnation.

Penetration. The penetration was recorded as the average of the penetration in from four to six increment-borer cores, taken in the center of the section and away from checks and knots. The depth of two types of penetration were measured as: complete type, the distance from the surface to the inside edge of the last consecutive growth ring in which both the spring and summer wood show visual signs of oil; ring type, the distance from the surface to the inside edge of the last consecutive summer wood ring which shows visual signs of oil. The depth of penetration was determined by splitting the borer core with the grain and inspecting the split surface. Du Pont Oil Soluble Red Dye was sprayed on the split surface (except sections 51 through 86) and the dye turned from a brown to a red color wherever there was oil.

Oil and water distribution. The oil and water distributions were determined by extracting the treated wood with benzene in a Soxhlet extractor equipped with a Dean-Stark water trap between the condenser and extraction tube. To obtain the samples, cuts were made about ¼ inch apart in the treated wood with a circular saw and the segment removed with a chisel. The flat segment was immediately cut into ½-inch increments, measured from the surface, the samples weighed (about 25 grams of sample were collected), and placed in the extraction apparatus and extracted for about six hours. After extraction they were dried in an oven and then reweighed. The weight of the oil was found by subtracting the weight of the water collected in the Dean-Stark trap during extraction from the total weight loss of the wood. (The resin content was found to be less than the analytical error.) The oil concentration was then calculated as pounds per cubic foot of wood, based on the wood density before treatment.

Bleeding. The surface of a treated section was considered to be dry of oil when the palm of a hand, firmly rubbed across the surface, removed only dry coloring matter; otherwise the section was considered wet. At times it was questionable whether the surface was dry or wet and these surfaces were classed as slightly wet. When the bleeding tendency of a section was to be observed it was kept in a building for four months, or until dry, and then placed vertically in a test plot on the west side of a sloping hill so that it would get the full effect of the afternoon sun. The bleeding characteristics were determined either by recording the number of days required to dry or the condition of the surface one day after treatment.

Results

The results are divided into the oil-water and pressure reduction treatments. The sections were treated by the Lowry method (introduction of the oil into the treating cylinder at atmospheric pressure) and an oil temperature of 150°F was used.

Oil-water treatment

The stages in the investigation consisted of: (1) the original treatments to determine the merit of the procedure (Table 1); (2) the effect of the oil to water ratio (Table 1); (3) the effect of lowering the water pressure (Table 1); (4) the introduction of water at high pressure (Table 1); (5) the development of a treating schedule applicable to commercial plants (Table 2). Oil and water distributions in the treated wood, as determined by extraction, are given in Figure 3 and in Appendix C, Table 13.

Pressure reduction treatment

The treating conditions and results of treatment are given in Table 3, and the oil and water distributions in the sections are shown in Figure 4 and in Appendix C, Table 14.

Discussion of Results

The results of the laboratory experiments are divided into the oil-water treatment, pressure reduction treatment, bleeding, and a discussion of the unsteady-state flow theory developed during the experiments.

Table 1. Conditions and results of oil-water treatme

Preservative: 5 per cent pentachlorophenol solution
Treating conditions: initial air pressure atmospheric, oil temperature 150°F, water introduced at atmospheric pressure unless otherwise noted

Pole sections
remainder c
Wood data: 9
10 1/8 in.

Section number	Pressure period, hour: oil, 150 psi	water 150 psi	water 50 psi	water at °F	Steam hr at 230°F	Vacuum hr at 22" Hg	Steam hr at	°F	Oil retention, lb per cu ft: gross pole	gross sapwood	net pole	net sapwo
1. Original treatments												
51	4.25	1.53	—	100	—	—	0.25	175	9.9	14.5	—	—
52	1.44	3.00	—	90	—	—	6.00	230	6.3	13.6	—	—
54	3.67	3.74	—	90	—	—	1.75	250	13.0	21.3	12.8	21.
57	2.48	2.28	—	130	—	1.10	0.75	230	9.0	15.6	—	—
65	4.02	2.00	—	90	—	1.00	0.33	250	7.6	24.0	—	—
2. Oil to water ratio												
96	2.95	1.60	—	100	—	2.00	—	—	8.0	13.0	—	—
97	2.50	3.00	—	100	—	3.00	—	—	5.4	7.7	—	—
98	3.95	1.75	—	100	—	—	2.13	250	5.1	7.9	—	—
99	2.68	2.67	—	100	—	—	6.61	260	9.7	14.1	—	—
3. Reduction of water pressure												
101	2.33	2.65	2.68	200	—	—	0.75	260	4.8	12.2	—	—
124	5.93	0.50	5.50	200	—	0.17	—	—	10.0	16.5	9.1	15.
123	3.85	0.50	1.50	200	0.25	0.50	—	—	8.9	14.8	8.5	14.
126	2.01	0.50	3.50	200	0.25	0.50	—	—	8.2	12.3	5.7	8.
120	4.22	0.50	5.75	200	0.25	0.50	—	—	8.2	12.0	—	—
125	4.06	0.50	6.50	200	0.25	0.50	—	—	8.6	16.5	8.6	16.
4. Introduction of water at high pressure												
4- 1	1.18	none			—	—	—	—	—	—	4.1	9.
4-12	1.20	none			—	—	—	—	8.2	17.0	6.1	12.
4- 2	2.80	none			—	—	—	—	7.0	15.3	6.3	13.
4- 3	2.90	2.03	—	200	—	—	—	—	—	—	8.4	17.
4-16	1.27	2.05	—	200	—	—	—	—	6.8	14.2	4.3	9.
4- 6	1.50	6.14	—	200	—	—	—	—	6.2	12.2	—	—
4- 9	2.30	2.07[c]	—	200	—	—	—	—	6.3	10.7	6.3	10.
4-18	1.96	4.00[c]	—	200	—	—	—	—	5.8	11.8	5.8	11.
4- 4	0.50	6.16[c]	—	200	—	—	—	—	5.8	12.0	5.8	12.
4-20	1.66	0.50[c]	3.50	200	—	—	—	—	6.6	14.0	6.6	14.
4- 7	1.29	0.50[c]	5.50	200	—	—	—	—	6.8	12.7	6.8	12.

a- Gross water retention
b- Negative water retention, indicating some oil lost during water phase of treatme
c- Water introduced at 150 psi

s and results of oil-water treatments, research phase

solution
tmosphere,
,
d

Pole sections: pole 4 mountain-type Douglas fir, remainder coast-type
Wood data: 9 to 17 per cent moisture, 6 1/8 to 10 1/8 in. diameter

team		Oil retention, lb per cu ft				Net water retention, lb per cu ft		Penetration, inches		Sapwood depth, inches	Days to dry
		gross		net							
at	°F	pole	sapwood	pole	sapwood	pole	sapwood	complete	ring		
,25	175	9.9	14.5	—	—	—	—	1 3/8	1 1/2	1 1/2	105
,00	230	6.3	13.6	—	—	—	—	7/8	7/8	1	0
,75	250	13.0	21.3	12.8	21.0	2.7	4.4	1 1/4	1 1/2	1 1/2	8
,75	230	9.0	15.6	—	—	—	—	1 3/8	1 3/8	1 3/8	16
,33	250	7.6	24.0	—	—	—	—	5/8	5/8	5/8	40
—	—	8.0	13.0	—	—	1.6[a]	2.6[a]	1 1/4	1 3/8	1 3/8	30
—	—	5.4	7.7	—	—	2.1[a]	2.9[a]	1	1 5/8	1 5/8	25
,13	250	5.1	7.9	—	—	0.8[a]	1.2[a]	3/4	3/4	1 3/8	0
,61	260	9.7	14.1	—	—	9.6[a]	13.9[a]	1	1	1 1/2	0
,75	260	4.8	12.2	—	—	—	—	1/2	1/2	3/4	0
—	—	10.0	16.5	9.1	15.0	0.6	0.9	1 1/8	1 3/8	1 3/8	30
—	—	8.9	14.8	8.5	14.0	b		1 1/4	1 3/8	1 3/8	30
—	—	8.2	12.3	5.7	8.6	0.3	0.5	5/8	7/8	1 5/8	0
—	—	8.2	12.0	—	—	—	—	1	1 3/8	1 5/8	0
—	—	8.6	16.5	8.6	16.5	0.1	0.2	1 3/8	1 3/8	1 3/8	30
—	—	—	—	4.1	9.0	none	none	1/4	1/2	1 1/4	-
—	—	8.2	17.0	6.1	12.7	none	none	3/8	5/8	1 3/8	-
—	—	7.0	15.3	6.3	13.6	none	none	5/8	1 1/4	1 1/4	-
—	—	—	—	8.4	17.5	1.1	2.2	1 1/4	1 1/4	1 1/4	-
—	—	6.8	14.2	4.3	9.1	1.0	2.0	3/8	5/8	1 3/8	-
—	—	6.2	12.2	—	—	—	—	1/2	1 1/4	1 1/4	-
—	—	6.3	10.7	6.3	10.7	0.5	0.9	1/4	3/4	1 1/2	-
—	—	5.8	11.8	5.8	11.8	1.8	3.7	5/8	1 3/8	1 3/8	-
—	—	5.8	12.0	5.8	12.0	3.4	7.1	5/8	1 1/4	1 1/4	-
—	—	6.6	14.0	6.6	14.0	b		3/8	1 1/8	1 3/8	-
—	—	6.8	12.7	6.8	12.7	0.8	1.4	1/4	1 1/4	1 1/4	-

lost during water phase of treatment or some of original water lost during treatment

Table 2. Conditions and results of oil-water treatm

Preservative: 5 per cent pentachlorophenol solution
Treating conditions: initial air pressure atmospheric oil temperature 150°F, water introduced at minimum oil temperature

Pole
rem
Wood
10

Section number	Duration, hour, of pressure period at psi: oil 150	oil 120	oil 90	water 150	water 90	water 50	water 25	water 15	water 0	Steam hr at 240°F	Vacuum hr at 22" Hg	Net oil retention, lb per cu ft: pole	sapwood
5. Development of commercial schedules													
4-21	1.05	0.95[a]	0.52[b]	3.20	—	—	—	—	—	—	—	5.2	10.9
32-1	1.84[c]	1.00[a]	1.40[b]	0.50	d	4.44	—	—	—	0.50	0.50	9.3	19.9
32-2	0.84	f		0.50	—	5.50	—	—	—	—	—	6.6	14.2
32-3	1.22	f		1.16	—	1.08	2.90	1.05	—	—	—	6.6	14.5
30-5	1.60	—	—	0.50	—	5.50	—	—	—	—	—	5.1	12.0
30-1	6.80	0.50	0.50	0.50	—	5.50	—	—	—	—	—	5.8	11.2
30-2	2.40	0.50	0.50	0.50	0.50[a]	1.00	2.00	1.00	1.00	—	—	6.2	11.8
30-3	1.30	0.50	0.50	—	2.00	1.00	1.00	1.00	1.00	—	—	6.2	13.2
30-6	0.50	g		—	2.00	1.00	1.00	1.00	1.00	—	—	7.1	18.2
30-4	—	—	2.40	—	2.00	1.00	1.00	1.00	1.00	—	—	5.1	12.1
35-1	6.00	0.50	0.50	0.50	—	5.50	—	—	—	—	0.50	6.7	11.1
35-5	5.02	0.50	0.50	0.50	—	5.50	—	—	—	0.50	0.50	2.4	4.8
35-4	16.10	0.50	0.50	—	2.00	1.00	1.00	1.00	1.00	—	0.50	7.4	16.6
35-6	16.26	0.50	0.50	—	2.00	1.00	1.00	1.00	1.00	0.50	0.50	9.2	17.9
35-2	1.00	h		—	2.00	1.00	1.00	1.00	1.00	—	0.50	5.1	8.8

a- 100 psi
b- 50 psi
c- Pressure reduced from 150 to 120 psi
d- Pressure held at 100 psi for 0.55 hr, then at 70 psi for 0.51 hr
e- Negative water retention, indicating some oil lost during water phase of treatı treatment
f- Pressure reduced to keep retention constant, minimum pressure 90 psi
g- Pressure reduced from 150 to 90 psi, 15 psi every 0.50 hr
h- Pressure reduced from 150 to 90 psi, 15 psi every 1.00 hr

ons and results of oil-water treatments, development phase

1 solution
 atmospheric
at minimum

<u>Pole sections</u>: pole 4 mountain-type Douglas fir, remainder coast-type
<u>Wood data</u>: 10 to 18 per cent moisture, 8 3/8 to 10 1/4 in. diameter

t psi		Steam hr at 240°F	Vacuum hr at 22" Hg	Net oil retention, lb per cu ft		Net water retention, lb per cu ft		Penetration, inches		Sapwood depth, inches	Surface, % wet one day after treatment
15	0			pole	sapwood	pole	sapwood	complete	ring		
—	—	—	—	5.2	10.9	5.1	2.5	1/2	1 3/8	1 3/8	100 wet
—	—	0.50	0.50	9.3	19.9	e		1 3/8	1 1/2	1 1/2	100 s. wet
—	—	—	—	6.6	14.2	2.2	4.6	1	1 1/8	1 1/2	100 wet
1.05	—	—	—	6.6	14.5	e		1 1/4	1 1/2	1 1/2	100 s. wet
—	—	—	—	5.1	12.0	1.7	4.1	7/8	1	1 1/8	100 wet
—	—	—	—	5.8	11.2	1.2	2.2	5/8	3/4	1 3/8	100 wet
1.00	1.00	—	—	6.2	11.8	e		1 1/8	1 1/4	1 3/8	60 wet
1.00	1.00	—	—	6.2	13.2	1.0	2.1	3/4	7/8	1 1/4	50 wet
1.00	1.00	—	—	7.1	18.2	e		1	1	1 1/8	90 wet
1.00	1.00	—	—	5.1	12.1	0.5	1.3	5/8	7/8	1 1/8	100 wet
—	—	—	0.50	6.7	11.1	0.7	1.1	3/4	1	1 1/2	25 wet
—	—	0.50	0.50	2.4	4.8	0.4	0.8	1/2	3/4	1 1/2	0 wet
1.00	1.00	—	0.50	7.4	16.6	3.1	5.6	7/8	1 1/4	1 1/2	5 s. wet
1.00	1.00	0.50	0.50	9.2	17.9	e		1 1/4	1 1/2	1 1/2	50 s. wet
1.00	1.00	—	0.50	5.1	8.8	0.3	0.5	5/8	7/8	1 1/2	0 wet

at 70 psi for 0.51 hr
il lost during water phase of treatment or some of original water lost during

, minimum pressure 90 psi
 every 0.50 hr
 every 1.00 hr

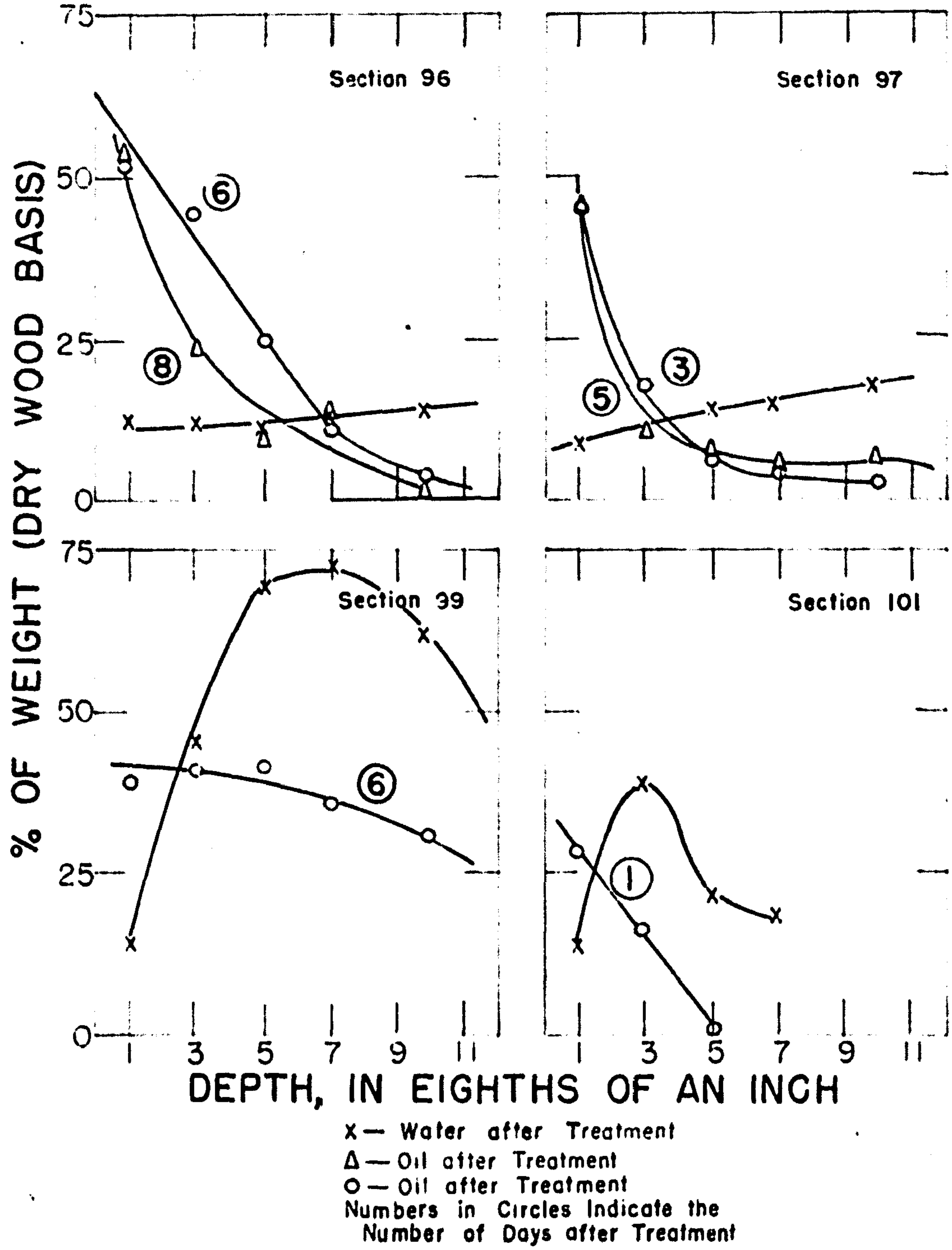

Figure 3. Oil and water distributions in oil-water treated pole sections

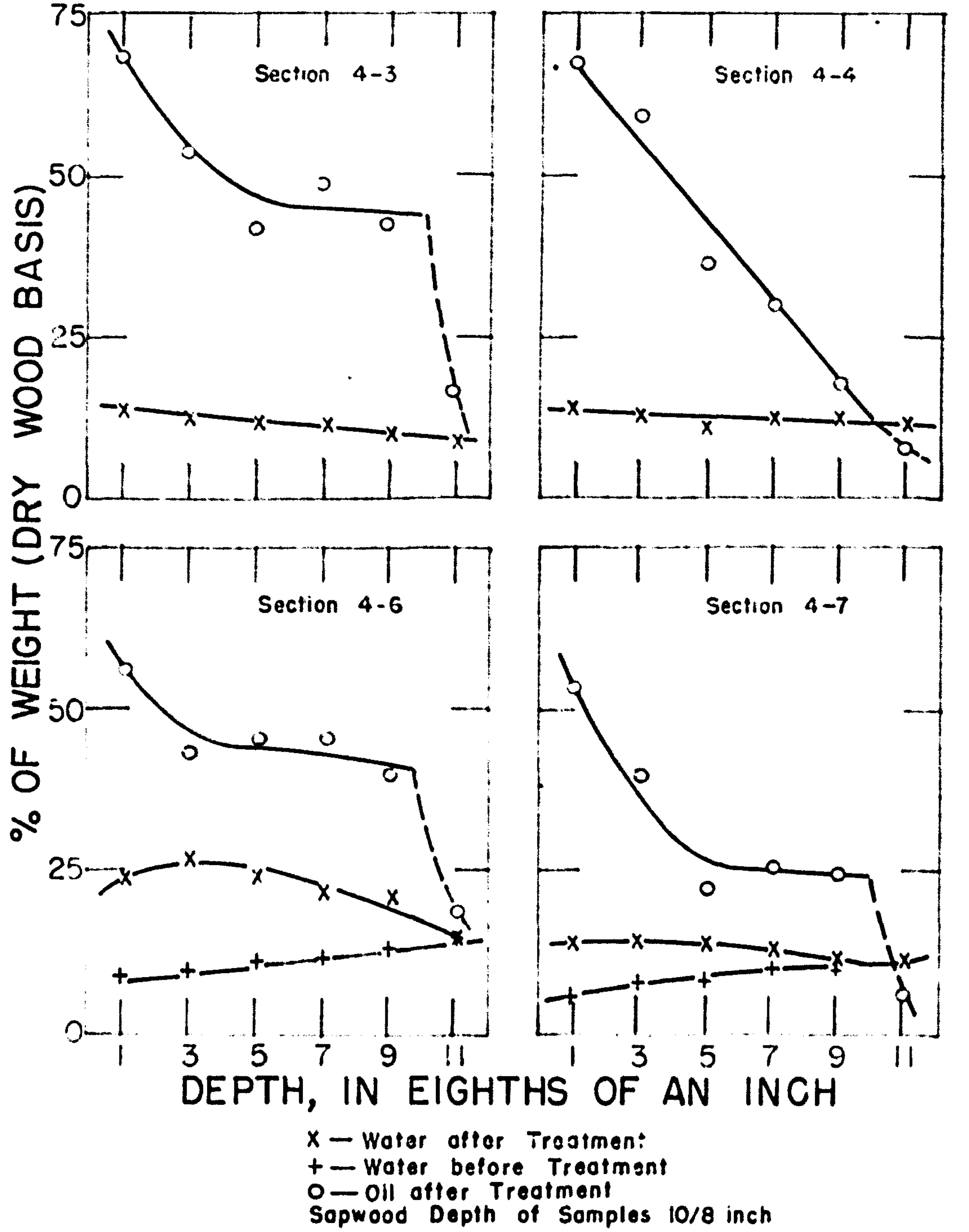

Figure 3. (Continued)

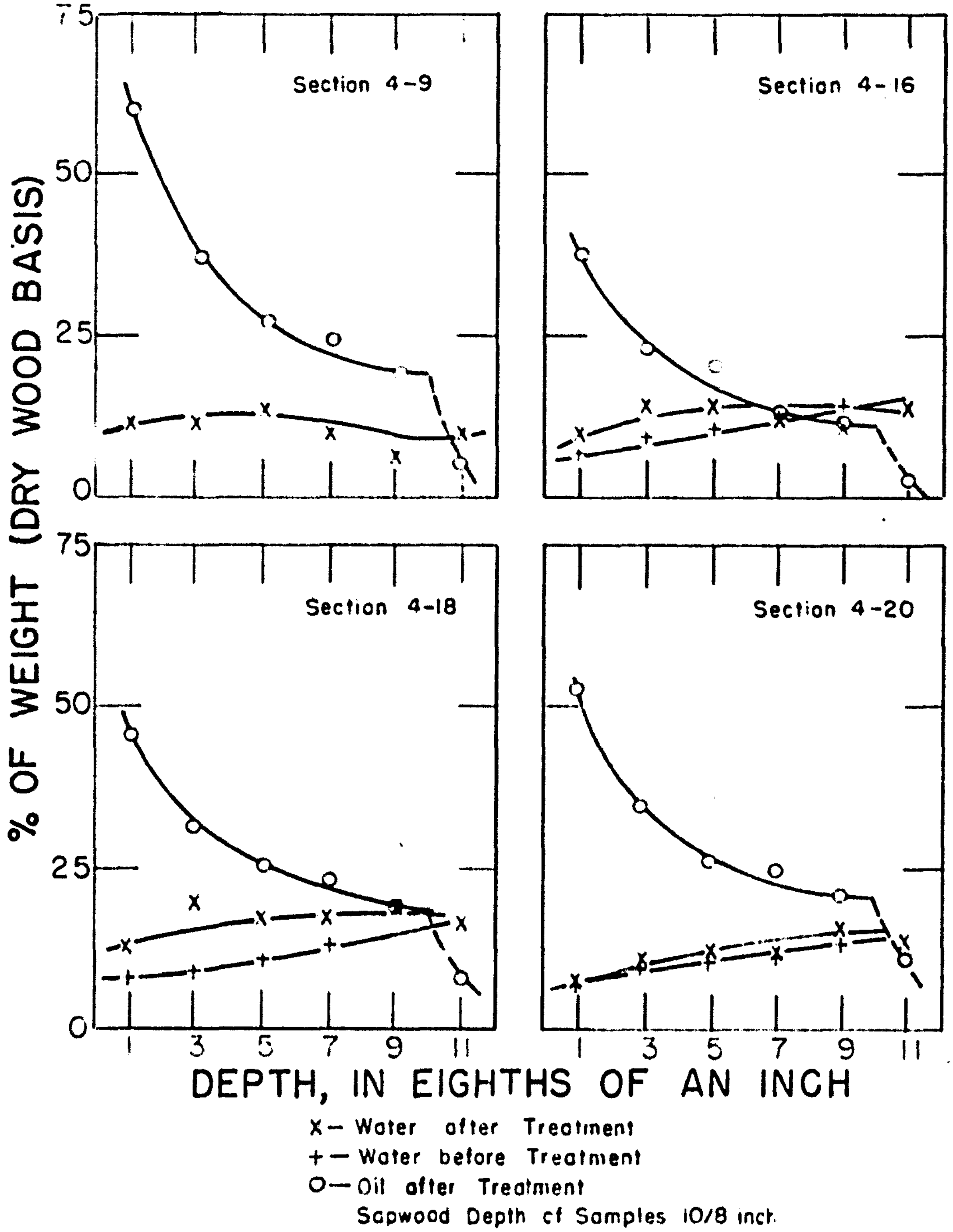

Figure 3. (Continued)

Table 3. Conditions and results of pressure reduction treatments
Preservative: 5 per cent pentachlorophenol solution
Treating condition: initial air pressure atmospheric, oil temperature 150°F
Pole sections: pole 4 mountain-type Douglas fir, remainder coast-type
Wood data: 9 to 18 per cent moisture, 7½ to 10 in. diameter

Section number	Pressure period: Hr at 150 psi	Reduced pressure: psi	Reduced pressure: per hr	Total time, hours	Net oil retention, lb per cu ft: Pole	Net oil retention, lb per cu ft: Sapwood	Penetration, inches: Complete	Penetration, inches: ring	Sapwood depth, inches	Surface condition
93	0.25	15	0.25	2.50	4.2	5.8	1/2	3/4	2	20 days to dry
86	0.50	15	0.50	5.30	6.4	9.5	1 3/4	1 3/4	1 3/4	35 days to dry
95	0.75	15	0.75	8.00	6.6	9.2	2	2	2	30 days to dry
94	1.00	15	1.00	11.02	6.6	9.5	1 3/4	1 7/8	1 7/8	30 days to dry
4-17	0.40	10	0.25	4.00	4.8	9.9	1/2	3/4	1 3/8	—
4- 8	0.50	10	0.50	7.50	6.7	11.9	1/4	1 1/4	1 3/8	—
4- 5	1.41	a		7.18	5.3	11.4	1/2	1 1/8	1 1/8	—
35- 3[b]	1.00	15	0.75	7.75	3.9	6.8	1/2	3/4	1 1/2	0% wet
35- 7[b]	1.00	15	1.00	10.00	6.2	12.9	1 1/8	1 1/2	1 1/2	50% s. wet

a- Pressure reduced to keep retention constant

b- Given final conditioning of: 0.50 hr steaming at 240°F followed by 0.50 hr vacuum at 22 in. Hg

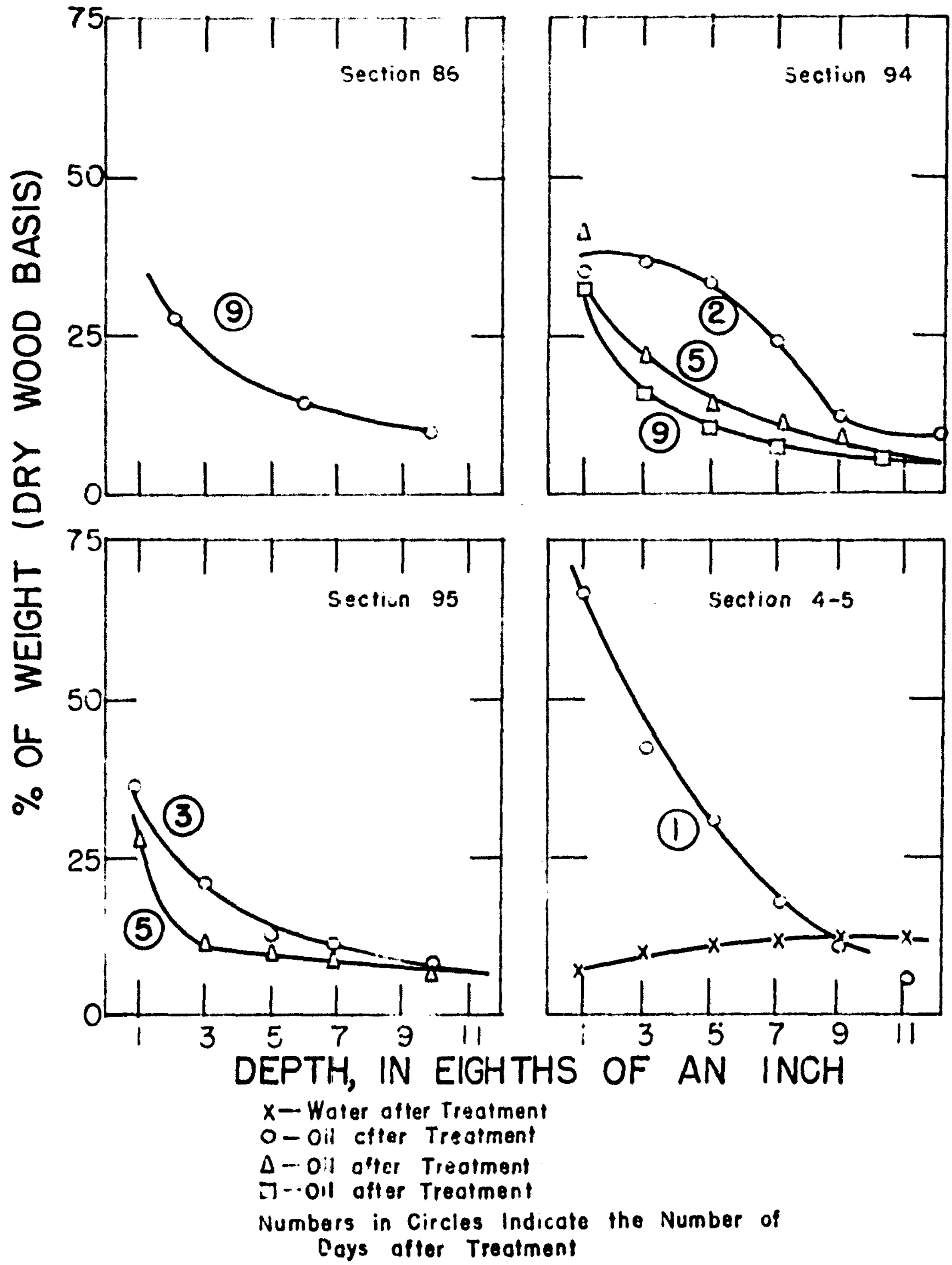

Figure 4. Oil and water distributions in pressure reduction treated pole sections

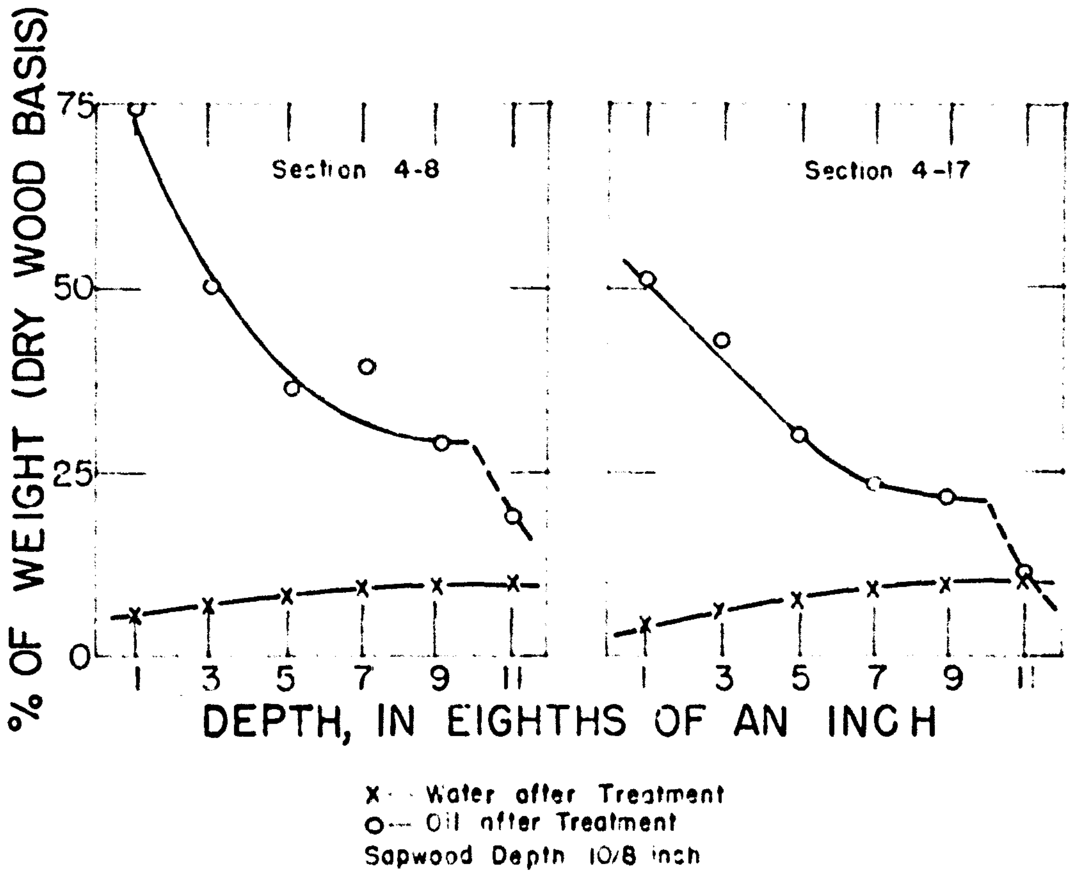

Figure 4. (Continued)

Oil-water treatments

The five stages of the oil-water experiments are discussed in chronological order.

Original treatments. The five pole sections originally treated to determine the effect of injecting water after oil gave results which indicated that further work along this line would be profitable.

Effect of oil to water ratio. The steady-state flow principle upon which the oil-water treatments were based would predict that the amount of injected water would affect the penetration and bleeding tendency; however, the oil to water ratio had no appreciable effect on the penetration and bleeding tendency. The oil and water distributions, determined shortly after treatment, indicated that the water flowed around the oil, rather than pushed it ahead. The surfaces of pole sections 98 and 99 were visually affected by the excessive steaming conditions.

Reduction of water pressure. This series was run to determine the effect of water pressure and temperature on bleeding. The bleeding tendency was reduced by decreasing the water pressure from 150 to 50 psi and raising the temperature from 150 to 200°F during the treatment. Under these conditions, plus a short steaming and vacuum cycle, dry sections were produced with a retention of 12 lb of oil per cu ft of sapwood.

<u>Introduction of water at high pressure</u>. The depth of penetration was increased when the oil to water change was made at 150 psi (the treating pressure of the oil) and when the duration of the water period was extended. The penetrations obtained by the oil-water treatment were greater than if the water treatment was not given. While the penetration of pole No. 4, mountain-type Douglas fir, appeared shallow for the retentions, a very high oil concentration was needed to visually detect the oil, as shown in Table 4.

<u>Development of commercial treatments</u>. The commercial plant, at which the oil-water treatment was to be tested, was limited to a maximum oil to water change pressure of 90 psi. In order to reduce the time of treatment an oil treating pressure of 150 psi was used and the pressure reduced to 90 psi. The most advantageous procedure was to reduce the oil pressure 30 psi every 30 minutes after the desired retention was obtained. Of two methods of reducing the water pressure, a gradual reduction from 90 to 0 psi in 6 hours produced drier sections than if the pressure was raised for the first 0.5 hour to 150 psi and then reduced to 50 psi and maintained for 5.5 hours. The latter method appeared to give better penetration. A short steaming and vacuum cycle after the water phase decreased the bleeding tendency.

Table 4. Average oil concentrations at the limit of ring and complete type penetration in mountain type Douglas fir sapwood[a]

Pole no.	Average oil concentration, %, at depth of penetration: Complete	Standard deviation	Ring	Standard deviation	Number of pole sections	Surface of pole sections
3	12.5	1.5	11	1.5	4	not incised
4	37	11	22	7	14	not incised
11	14	4	8	b	6	not incised
3A	16	c	11	c	2	1 section incised
8	16	4	7	4	5	not incised
8	17	4	10	6	4	incised

a- The average oil concentration was found by extracting ½ inch increments of wood cut from a segment of treated wood and plotting the per cent by weight oil concentration in each increment vs the average depth of the increment. The average depth of penetration was calculated from the depths measured in from four to eight increment borer cores and the oil concentration at this depth was read from the oil distribution curve. All pole sections were treated by surrounding the wood with oil at atmospheric pressure before applying pressure. The pole sections were treated by the oil-water and pressure reduction methods as well as oil impregnation with and without steaming and vacuum and the results are the averages of the various methods.

b- Too many pole sections had 100 per cent ring type penetration to calculate standard deviation.

c- Too few pole sections to calculate standard deviation.

Pressure reduction treatments

The pressure reduction treatments, based on the unsteady-state flow principle, gave deep penetrations with light oil retentions. The data indicate that a satisfactory retention can be obtained in coast-type Douglas fir if the pressure is reduced 15 psi every hour. This treatment reduced the bleeding tendency.

The rate of oil retention tended to remain the same, as the pressure was reduced, as if the pressure were kept at 150 psi, until a pressure of 50 psi was approached. This tendency was greater as the time between pressure reductions decreased, that is, as the total treating time was reduced. The rate of retention in all sections approached zero at 50 psi and, with further reduction in pressure, most sections expelled oil.

It is more difficult to obtain a desired retention by a systematic reduction in pressure, but a second method, treating to the desired retention and then reducing the pressure so as to keep the retention constant, while producing deep penetrations, is probably not as applicable to commercial production as the first.

The pressure reduction treatment produces deep penetrations and reduces the tendency to bleed. However, a steaming and vacuum cycle is necessary to assure a minimum amount of bleeding.

Bleeding

Bleeding is caused by a pressure differential forcing oil to the surface of the wood. Two types of bleeding can occur: "residual," caused by the air pressure left in the wood after treatment; and "solar," caused by a rise in the surface temperature of the wood. If the wood surface is not free of oil after treatment, and all the oil does not readily evaporate, an objectionable oily surface will result; however, this is seldom the case in commercial treatment and it can hardly be considered bleeding.

Residual bleeding. Residual bleeding usually commences a day after treatment and the oily surface may continue for several days or a number of months. The weight loss (a measure of residual bleeding) of sections treated at 150 psi and 150°F (oil introduced at atmospheric pressure), and given no water injection or any other final conditioning, varied as the 0.45 power of time and directly as the oil retention based on the treated volume; below a retention of 6 lb per cu ft of treated wood no weight loss or bleeding occurred.

In the experiments only residual bleeding was considered (although solar bleeding was determined) as this gave a rapid, and, it is believed, an accurate indication of bleeding tendency. No residual bleeding tendencies of pole No. 4 were determined as the experiments were made to determine the effect of treating conditions on penetration and no attempt was made to produce dry poles.

Solar bleeding. Because solar bleeding is dependent on the surface temperature, it may occur for several years. While poles which show great residual bleeding tendencies are more apt to solar bleed, non-residual bleeding poles may solar bleed.

The only sections treated by the oil-water and pressure reduction treatments which showed signs of solar bleeding were the oil-water treated sections 54, 57, and 65. Sections 54 and 57 had a heavy streaked coating of material which was not tacky but indicated that solar bleeding may have occurred. Section 65 was tacky in streaks. All sections were dry, however, after one year in the pole test plot.

While no experiments have been made to determine the effect of the wood and treating conditions on solar bleeding, it appears that, once residual bleeding has ceased, the physical properties of the wood have more of an effect on solar bleeding than the treating conditions or the retention.

Unsteady-state flow

The effect of treating conditions on the penetration and the bleeding tendency can be predicted if the type of liquid flow in wood is known. The flow is either steady-state, when the mass of liquid entering a small volume of wood is equal to the mass leaving, or unsteady-state, when the mass entering is not equal to that leaving, that is, there is an increase or depletion of liquid in the small volume of wood.

Proof of unsteady-state flow. If steady-state flow occurred in the normal impregnation of wood it would manifest itself with a moving boundary. The conditions for steady-state flow and its effect on the results of treatment can be determined from the known equations. If these conditions and results are contrary to those observed, then steady-state flow cannot exist and, therefore, unsteady-state flow is proved. The conditions necessary for, and predictions resulting from, steady-state flow can be compared with the experimental observations with regard to time, oil distribution, and internal wood pressure.

Time. If steady-state flow with a moving boundary occurred, then the retention would vary approximately as the square root of the time, provided that the temperature and pressure remained constant. (If impregnation was into an infinite plane then the retention would vary as the square root of time; in the case of a 10-inch diameter pole, the retention due to radial flow is calculated to vary as the 0.482 power of time, within the range of retention normally obtained in the treating industry.) The laboratory experiments showed that the rate of the retention in the pole sections ranged from the 0.29 to 0.54 power of time and averaged 0.38. The high value of 0.54 is probably due to an inaccuracy in measuring the rate of retention, rather than the actual rate of retention being greater than the square root of time. Some of the sections were highly checked, which would cause a decrease in the power of time; MacLean's data (33), obtained by impregnation of sawed timbers, which had no checks, showed that the retention varied as the 0.35 power of time. The steady-state flow theory is not compatible with these observations.

Oil distribution. If steady-state flow occurred, the last liquid to enter the wood would be concentrated in the outer layers and, from a consideration of pore sizes in the wood, the liquid distribution would take the shape of a concave upwards parabolic curve. Because they were made a day after treatment, the extraction data of the oil-water treatments are not a completely accurate indication of the distribution immediately after treatment; however, they show that the increase in water is fairly evenly distributed in the treated portion of the wood and the distribution line of the increase in moisture content is concave downward, which is contrary to the steady-state flow predictions.

The steady-state flow theory would not require a uniform oil distribution if the effective flow occurred through a number of radial tubes, each with a different flow resistance. While the oil concentration in each tube would be the same, the overall effect would be that of a decreasing oil gradient, high at the surface and lowest at the depth of penetration; the retention would still vary as the square root of time.

Internal wood pressure. If steady-state flow occurred and each cavity were completely filled with liquid, then the treating pressure would have no effect on the average oil retention per cubic foot of treated wood, which is contrary to the observations. Therefore, to have steady-state flow each cavity must be only partially filled with liquid, and the fraction of the void volume filled with liquid must be constant at any one point (but not necessarily the same as every other point) for the entire pressure period after the liquid has entered the section. During the pressure period the pressure within the wood at a given point will increase. To keep the volume of air the same (and, therefore, the fraction of the cavity filled with oil constant), additional air would have to be introduced into the cavity. There is no source from which this additional air could come other than other cavities under high pressure. As a result, the fraction of the cavities filled with oil would increase and unsteady-state flow conditions would prevail.

The steady-state flow theory is not compatible with the observations and therefore unsteady-state flow exists in Douglas fir.

Predicted effect of treating conditions. The effect of treating conditions on bleeding and penetration in Douglas fir can be estimated from the unsteady-state flow principle. For purposes of visualization only, assume that flow occurs through a number of radial tubes, and that at right angles to these tubes are a number of cavities, only open to the adjacent tube. Further, assume that the cross sectional area of the radial tubes is negligible and the volume of the cavities represents the void volume of the wood. In such a system all the air would be trapped in the cavities and none pushed ahead of the entering liquid.

Before discussing the effect of treating conditions on penetration and bleeding, the interrelationship between retention, penetration, and average oil concentration should be understood. The average oil concentration is defined as the fractional part of the average void volume of the treated part of the wood filled with oil. Therefore, for a given retention, a reduction in the average oil concentration will increase the penetration; if the average oil concentration remains constant, an increase in total retention will increase the penetration.

The effect of treating conditions can now be more easily visualized.

<u>Pressure</u>. Table 5 shows the effect of the initial air pressure and the final pressure in a cavity on the oil concentration (fraction of the void volume filled with oil). The oil concentration is decreased by a reduction in final pressure or an increase in initial pressure. Since the final pressure is determined in part by the impregnation pressure, a reduction in the impregnation pressure will reduce the oil concentration.

After treatment the compressed air in the cavities will expand to push the oil both towards the pole surface and the pole center, and the higher the pressure of this compressed air, the greater will be the "creepage" or increase in penetration after treatment. While lower treating pressures would produce deeper penetrations immediately after treatment, within certain pressure ranges an increase in pressure might produce sufficient creepage to give a deeper penetration sometime after treatment. Because creepage is dependent on the high internal pressure near the wood surface, any reduction of this pressure by steaming, vacuum, or expansion bath, will reduce the creepage tendency.

Bleeding is caused by the same internal pressure caus-

Table 5. Relationship of pressures to calculated oil concentration in a cavity

Final pressure (atmospheres)	Calculated[a] oil concentration[b] when the initial gas pressure (in absolute atmospheres) is			
	0.5 (15 in. Hg vacuum)	1.0 (atmospheric)	3.0 (29 psig)	5.0 (59 psig)
1	0.50	0.00	——	——
2	0.75	0.50	——	——
3	0.83	0.67	0.00	——
4	0.88	0.75	0.25	——
5	0.90	0.80	0.40	0.00
6	0.92	0.83	0.50	0.17
7	0.93	0.86	0.57	0.29
8	0.84	0.88	0.62	0.38
9	0.94	0.89	0.67	0.44
10	0.95	0.90	0.70	0.50

a- Calculated from the following equation:

$$C = (P_2 - P_1)/P_2$$

where C is the calculated oil concentration
P_1 is the initial pressure, in atmospheres
P_2 is the final pressure, in atmospheres

b- Fraction of void volume filled with oil ing creepage and therefore a reduction of treating pressure, a reduction of initial air pressure, or application of steaming, vacuum, or expansion bath reduces the bleeding tendency.

The high internal wood pressure can increase the penetration if the treating pressure is reduced so that most of the air expansion in the cavities is utilized to force the oil farther into the wood. One way to do this is to reduce the pressure so that the retention remains constant; another is to reduce the pressure so that oil continues to enter the pole, but very slowly, until a low pressure, such as 50 psi, has been reached.

Temperature. The rate of retention is partially dependent on the oil viscosity. The viscosity will decrease with an increase in temperature and therefore the rate of retention will increase; this, however, should not affect the oil distribution. However, because of the moisture content of wood, an increase in temperature will result in an increase in the internal vapor pressure, and, consequently, a lower oil concentration. Below 150°F its effects should be negligible, but at temperatures above 150°F its effects should be noticeable. As the wood cools after treatment, the steam pressure decreases and the bleeding tendency resulting from the Rueping-type of treatment should not occur.

Preheating or steaming the poles before treatment will produce this effect. An expansion bath or steaming after treatment will also generate additional internal pressure with beneficial results.

Retention. For a given retention, the penetration is a linear function of the average oil concentration, but the relationship between retention and penetration is more complex. During the first part of the impregnation process, when the depth of penetration is very slight, a steep pressure gradient will occur and this gradient will decrease as the retention, and therefore the penetration, continues to increase. Since the majority of oil flow into a cavity occurs when the cavity is under low pressure, say up to 5 atmospheres, only a little of the oil that enters the wood will enter the cavities under high pressure (those near the surface) and most of it will continue farther into the wood to fill the cavities at lower pressure. Therefore, an increase in retention of 2 lb of oil per cu ft of pole will produce a larger increase in penetration between an 8 and 10 lb than between a 2 and 4 lb retention. An increase in retention resolves into an increase mainly in the interior of the wood and not in the outer layers.

Limitations of theory. To further the illustration of the unsteady-state flow theory, an extreme case, in which all the air was trapped in the cavities, was used. While theoretically either steady-state or unsteady-state flow occurs, the effective result will be somewhere between the two. As less air is trapped in the cavities and more pushed ahead of the oil, steady-state flow will be approached and the effect of pressure, temperature, and retention on the average oil concentration will decrease. While the permeability of the wood is no criterion for judging the type of flow, it is probable that the more permeable wood will tend more towards steady-state flow. Therefore pressure would be expected to have less effect on the oil concentration in southern pine than in Douglas fir.

The type of flow will be affected by the treating conditions, and will approach steady-state flow as the impregnation pressure approaches the internal pressure, or as the amount of compressible gas in the wood is reduced. Then steady-state flow would be approached at low treating pressures and when a preliminary vacuum is used.

COMMERCIAL SCALE EXPERIMENTS

In the laboratory, the oil-water and pressure reduction treatments showed promise of increasing the penetration and reducing the bleeding tendency so their effectiveness was tested on a commercial scale.

The Utilities Research Commission of Chicago arranged for the Joslyn Manufacturing and Supply Company to treat five charges of coast-type Douglas fir poles at its plant in Franklin Park, Illinois. After treatment the poles were placed near Joliet, Illinois, in a power line belonging to the Public Service Company of Northern Illinois.

The discussion of these commercial scale treatments includes the plan of investigation, equipment, supplies, collection of data, treating schedules, results, comparison of results, and discussion of results.

Plan of Investigation

Of the experimental charges planned, three were to be oil-water treatments and one, a pressure reduction treatment. A conventional charge, treated in accordance with the company's standard practice, would act as a "control." Two schedules of reducing the water pressure during the oil-water treatments were planned. One oil-water charge was to receive a net retention of 8 lb of oil per cu ft of pole, while the other three charges and the control were to receive a net retention of 6 lb of oil per cu ft of pole.

Since this program was designed to indicate the effect of water pressure on penetration and the effect of the experimental methods of treatment on penetration and bleeding, the duration of the treating schedules and the steaming periods was probably longer than necessary. However, due to unforseen conditions, the program could not be carried out as planned.

Detailed observations of the poles before and after treatment which allow evaluation of the experimental treatments through comparison of the penetration and bleeding tendencies are, with their correlations, discussed in a later section.

Equipment

Standard commercial equipment was used in these treatments. As in the normal practice of the plant, the treating oil flowed from a Rueping tank into the cylinder filled with wood. Additional oil was then pumped in from a small measuring tank to develop pressure, and the reduction of oil in the measuring tank showed the amount of oil injected during the pressure period.

During the oil-water treatments the oil was stored in the tank farm, and the water, in the Rueping tank. After the oil period, compressed air was introduced to blow the oil (including that in the measuring tank) back into the supply tank. Then the cylinder and the measuring tank were filled with water which was, on completion of the water period, returned to the Rueping tank.

The accuracy of the oil and water readings in the measuring tank was approximately plus or minus 75 pounds, and that of the oil in the storage tank was approximately plus or minus 150 pounds.

Supplies

Only the poles and the treating oil are included in this discussion.

Wood

The poles were coast-type Douglas fir and, excepting one from the plant stock, all had been delivered at the plant within a month of the treatments and were semi-air dry. Each of the 164 poles was machine shaved, and a 6-foot section of the butt end, from 2 feet below the ground line to 4 feet above it, was incised. The poles were also roofed, gained, and bored before treatment, and they showed considerable variation in degree of checking, number and size of knots, growth rings per inch in the sapwood, and sapwood depth. In size they ranged from a 30-foot class 7 to a 50-foot class 1.

The average moisture content of the first charge, measured by refluxing cores removed from the sapwood with toluene, was 26.8 per cent on a dry wood basis, and 17 per cent by an electric moisture meter using 5/32 inch prongs. The discrepancy in moisture contents is due to the differences in sampling depths. The moisture contents of the other charges, as measured by the meter, were approximately the same.

Oil preservative

The oil preservative was the same as that used in the laboratory experiments; the average pentachlorophenol content was 5.06 per cent by weight.

Collection of Data

Data were collected on the poles and pentachlorophenol assays were made.

Pole

Before treatment the circumference and the heartwood diameter at the butt and top of each pole were measured, and the poles were weighed. Their moisture contents were measured by an electric moisture meter. For identification, a numbered tag was placed above the brand line and on the top of each pole.

After treatment the poles were reweighed and the penetration measured in three cores removed from the incised groundline and in four cores from an unincised area near the brand, hereafter called the midpoint.

Pentachlorophenol analysis

Two cores from each pole, one from the incised groundline and one from the non-incised area directly below the brand, were used for the pentachlorophenol analyses. To facilitate analysis all groundline cores from a charge were placed in groups of about five each and sectioned into the first quarter-inch, the second quarter-inch, the second half-inch, and the third half-inch. The untreated part of the core was removed and only the penetrated wood or the sapwood, whichever was less, was analyzed. The midpoint cores, in exactly the same groupings as the groundline cores, were sectioned by the same procedure.

The company's standard lime ignition method of pentachlorophenol analysis, described in Appendix B, was used on the first four charges, and the fifth charge cores were analyzed by the Dow Chemical Company.

Mr. Noel Kittell, of the Joslyn Manufacturing and Supply Company, measured the penetrations of the first charge under the author's observation, and Mr. Howard Eddy, Inspector for the Public Service Company of Northern Illinois, measured the penetrations of the four experimental charges.

Treating Schedules

Although it was originally intended to use treating schedules developed in the laboratory experiments, the high moisture content of the poles made it advisable to modify those schedules by the inclusion of a 2-hour heating period prior to the application of pressure. A flash steaming was also incorporated, after the final vacuum, to assure that the poles would be free of oil film upon removal from the cylinder. Since the laboratory work with the pressure reduction treatment primarily concerned increasing penetrations rather than eliminating bleeding, the 30 minute steaming schedule was dropped in favor of the treating company's standard steaming schedule of 2.5 hours.

The first of the five charges was treated according to the company's standard practice, to act as a control. The second, third, and fourth charges received oil-water treatments, and the fifth received a pressure reduction treatment. Due to the newness of the treatment and certain malfunctions of the equipment, the schedules for the oil-water treatments could not be met. In the first oil-water treatment, Charge 2, the discrepancy was so great that the author elected to treat Charge 4, which was originally intended to be an 8 pound treatment, by the schedule of Charge 2. With the removal of the 8 pound treating schedule, all treatments were then intended to retain approximately 6 lb of oil per cu ft of pole.

The poles reached the desired retention more quickly than anticipated and while this did not materially affect the treating schedules of the water charges (excepting the estimated duration of the 150 psi pressure periods), it did achieve higher retentions than expected. However, it necessitated decreasing the schedule rate of pressure reduction by about one third in the pressure reduction treatment, Charge 5. The desired and the actual treating schedules are given in Table 6.

Results

Although the penetration can be easily calculated from its depth in the groundline and midpoint cores, the average computed value of the retention is dependent upon the method of calculation. The volume of the wood can be computed from tables prepared by the Office of Price Stabilization or calculated from the dimensions of the poles. The weight of the retained oil can be estimated from the gauge readings of the oil tanks or by the weight

TABLE 6. Desired and actual treating conditions of five charges of partially air seasoned coast-type Douglas fir poles with 5 percent solution of pentachlorophenol.

Charge no.	1		2		3		4		5	
	Des.[a]	Act.[a]	Des.	Act.	Des.	Act.	Des.	Act.	Des.	Act.
Fill cylinder with oil, hr.	0.25	0.25	0.25	4.50	0.25	0.25	0.25	0.25	0.25	0.25
Hot bath (150-160 F), hr.	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Pressure Period										
Time to Maximum press., hr.	1.00	1.00	0.25	0.15	0.25	0.80[b]	0.25	0.40[b]	0.25	0.30
maximum pressure, psi	125	125	150	150	150	150	150	150	150	140+
duration at max. press., hr.	2.00	2.00	3.00	0.15	3.00	2.30	3.00	1.30	1.00	0.05
duration at 120 psi, hr.	—	—	0.50	0.50[b]	0.50	0.50	0.50	0.50	g	h
duration at 90 psi, hr.	—	—	0.50	0.50[b]	0.50	0.50	0.50	0.50		
Replace oil with 90 psi air, hr.	-	—	0.50	2.50[c]	0.25	0.85	0.50	0.70	—	—
Replace air with 200 F water, hr.	-	—	0.25	0.25	0.25	0.25	0.25	0.25	—	—
Duration at 150 psi, hr.	—	—	0.50	0.85	—	—	0.50	0.50	—	—
Duration at 90 psi, hr.	—	—	—	—	2.00	2.00[bd]	—	—	—	—
Duration at 50 psi, hr.	—	—	5.50	5.50	1.00	1.00	5.50	5.50[e]	—	—
Duration at 25 psi, hr.	—	—	—	—	1.00	1.00	—	—	—	—
Duration at 15 psi, hr.	—	—	—	—	1.00	1.00	—	—	—	—
Duration at 0 psi, hr.	—	—	—	—	1.00	1.00	—	—	—	—
Remove water from cylinder, hr.	-	—	0.25	0.25	0.25	0.25	0.25	0.25	—	—
Steam										
To exhaust air, hr.	none	none	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
To 240 F, hr.	2.50	2.50	0.50	0.30	0.50	0.50	0.50	0.50	2.50	2.00
At 240 F, hr.	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vacuum, at 22" Hg minimum, hr.	0.75[i]	0.60[i]	0.50	0.25	0.50	0.15	0.50	0.30	0.50	0.20
Flash Steam (1/4 hour after air is exhausted), hr.	—	—	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Total duration, hours[j]	10.25	10.00	15.50	20.25	15.50	15.75	15.50	15.25	15.75	12.00

a- Des. - desired treating schedule, act. - actual treating schedule
b- Pressure could not be maintained due to malfunction of the pump
c- Pressure fluctuated between 75 and 90 psi.
d- Failure of steam and compressed air, pressure fell to 70 psi.
e- Average pressure was 60 psi.
f- Due to malfunction of pump only 140 psi could be maintained.
g- Pressure reduction of 15 psi every hour
h- Pressure reduction approximately 15 psi every 20 minutes
i- The vacuum period came immediately after the oil period and before the steaming.
j- Total time of treatment, not the sum of the durations listed in the table.

gains of the poles. The average retention equals either the total weight of retained oil (as estimated above) divided by the total volume of the poles, or the average of the individual retentions. (See Table 7.)

Table 7 shows the gross oil injection in the pressure period, the net oil absorption, and the gross water injection. All are based on the gauge readings and the calculated volume. (Gauge reading retentions are all based on the total oil divided by the total volume.)

The physical properties of each pole and its penetration and retention are in Appendix D, and the average retentions and penetrations for each of the charges are in Table 8. (Average retentions in Table 8 are the average of the individual pole retentions, and the latter are obtained by dividing the weight gain of the pole by its volume or surface area.)

Of the 164 poles treated only no. 99 was wet and only in spots which dried within several days. Weather conditions at the time of treatment impair the drawing of valid conclusions regarding the cleanliness of the treatments on the basis of one wet pole. The cleanliness of the treatment cannot be judged by the slight sludge deposits on the oil-water treated poles either, since the sludging resulted more from the newness of the treatment than from its inherent characteristics. (This deposit is expected to wash off in the first heavy rain.)

Table 7. Retentions, by several methods of calculations

	Charge number				
	1	2	3	4	5
Volume, cu ft					
O.P.S. tables	619.1	643.9	798.9	692.8	590.9
calculated	615.8	647.8	806.0	686.2	608.3
Oil, lb					
gauge readings	3,920	5,582	4,927	5,005	6,030
wt gain of poles	3,863	4,092	4,929	5,081	2,880
Final oil retention, lb per cu ft pole					
gauge & O.P.S. volume	6.34	8.67	6.17	7.23	10.21
wt gain & calc. volume	6.26	6.31	6.11	7.40	4.73
gauge & calc. volume	6.36	8.61	6.11	7.30	9.91
av. individual poles[a]	6.44	7.22	5.88	7.66	4.82
Oil retention, lb per cu ft pole[b]					
heating period[c]	0.00	0.78	0.00	0.23	3.26
pressure period[d]	9.30	7.83	6.37	7.07	6.65
loss during vacuum[c]	2.94	0.00	0.26	0.00	0.00
Gross water retention, lb per cu ft pole[b]	—	26.80	e	1.72	—

a- Weight gain and calculated volume. See Table 8
b- Gauge readings and calculated volume
c- Actual absorption is unknown, but is the amount listed plus an unknown quantity "Y". Likewise the actual loss during vacuum is unknown, but is the amount listed plus "Y".
d- Only that oil which entered the wood during the pressure period
e- Could not be measured for this charge but probably amounted to only several pounds per cubic foot of pole

Table 8. Average retentions and penetrations

Charge number	Average[a] moisture, %	Retention, av. lb wt gain per[b] cu ft		sq ft	Av. midpoint penetration[c] inches			% of sap.[d]		Av. groundline penetration[c] inches			% of sap.[d]	
		pole	sap.	surface	comp.	ring	sap.	comp.	ring	comp.	ring	sap.	comp.	ring
1	17	6.44	12.37	1.30	0.92	1.17	1.43	64	82	1.08	1.26	1.42	76	89
s[e]		1.38	3.45	0.28										
v[f]		21.4	27.9	21.5										
2	19	7.22	13.87	1.46	0.80	1.13	1.28	62	88	0.98	1.26	1.28	77	98
s		3.12	4.64	0.54										
v		43.2	33.6	36.6										
3	20	5.88	12.39	1.23	0.81	1.01	1.14	71	89	1.02	1.15	1.16	88	99
s		2.19	4.20	0.50										
v		37.2	33.9	40.7										
4	19	7.66	13.49	1.40	0.97	1.13	1.18	84	96	1.12	1.24	1.25	90	99
s		1.83	3.72	0.43										
v		23.9	27.6	30.9										
5	18	4.82	9.74	0.98	0.62	0.99	1.23	50	81	0.84	1.16	1.37	61	85
s		1.38	2.90	0.34										
v		36.3	29.8	34.4										

a- By electric moisture meter with 5/16 inch prongs
b- Average of individual pole retentions
c- Average of average depth of penetration in individual poles
d- Division of average penetration by average sapwood depth and multiplying by 100
e- Standard deviation, lb per cu ft or lb per sq ft
f- Coefficient of variation, per cent

Of all the poles treated only one, no. 144, did not meet the specifications of the Public Service Company of Northern Illinois. It had a very low retention, 1.56 lb of oil per cu ft of pole, and resultant poor penetration. The variation in retention in a charge allows such a low retention to occur with the probability that it results not from treating conditions but from abnormalities of the wood.

The average pentachlorophenol content of each charge is shown in Table 9, and the average contents of each group of about five poles are in Appendix E.

Comparison of Results

The object of treatment is to impregnate a pole with a quantity and depth of preservative sufficient to assure it a long, clean-surfaced life. At present, the life span of a pole cannot be accurately estimated from either the retention or distribution of the preservative, but they present a means of estimating the quality of treatment even though no uniform, industry-wide agreement on their minimums exists.

On the assumption that the control charge truly represents the conventional high pressure method of treatment, the experimental oil-water and pressure reduction treatments are compared with it, though with respect for the limitations involved.

Table 9. Concentrations of dry pentachlorophenol

Charge number	Lb[a] of dry pentachlorophenol per cu ft of sample[b] occurring in the zones[c]			
	0-¼"	¼-½"	½-1"	1-1½"
	Incised groundline			
1 (control)	1.117	0.986	0.667	0.434
2 (oil-water)	1.132	0.968	0.641	0.531
3 (Oil-water)	1.249	0.956	0.654	0.436
4 (oil-water)	1.199	1.046	0.702	0.502
average 2, 3, 4	1.193	0.990	0.666	0.490
5 (pressure reduction)	1.095	0.882	0.399	0.175
	Non-incised midpoint			
1 (control)	1.204	0.980	0.552	0.452
2 (oil-water)	1.103	0.873	0.585	0.457
3 (oil-water)	1.280	0.822	0.538	0.399
4 (oil-water)	1.220	0.994	0.612	0.459
average 2, 3, 4	1.201	0.896	0.578	0.438
5 (pressure reduction)	0.982	0.576	0.233	0.115

a- Weighted average, calculated by dividing total pounds of dry pentachlorophenol in zone by total volume of wood in zone analyzed

b- No untreated sapwood nor any heartwood was analyzed

c- Measured from surface of poles inward

Oil-water treatments

The oil-water treatments, Charges 2, 3, and 4, are compared, for penetration, retention, and pentachlorophenol distribution, with the control charge.

Penetration. Ring type penetration is used in the comparisons because of its industry-wide acceptance. Visually detected oil is assumed to contain a lethal concentration of pentachlorophenol. Because the control's average depth of penetration was equal to or greater than the average sapwood depths of the oil-water treated poles, three methods of comparison are used: the per cent of poles not meeting certain specifications; the average per cent of sapwood depth penetrated in poles grouped by sapwood depth; the estimated depth of penetration if the experimental charges and the control had the same average sapwood depths.

The five specifications and the number and per cent of poles in each charge that did not meet them, at the non-incised midpoint and the incised groundline, are listed in Table 10. At the groundline about the same percentage of poles from the control and the oil-water charges does not meet specifications A, B, and C; and a larger percentage of the control does not meet specifications D and E. At the midpoint a smaller percentage of the control charge

Table 10. Number of poles not meeting penetration specifications

Charge number	A[a] no.	A[a] %	B no.	B %	C no.	C %	D no.	D %	E no.	E %
	Number and per cent of poles in charge									
Incised groundline										
1 (control)	0	0	1	3	5	15	7	21	21	63
2 (oil-water)	0	0	3	10	5	17	4	14	9	31
3 (oil-water)	0	0	2	5	3	8	4	11	6	16
4 (oil-water)	1	2	1	2	4	10	7	17	8	20
av. 2, 3, 4	-	1	-	6	-	12	-	14	-	23
5 (pressure reduction)	0	0	1	4	4	17	6	25	16	67
Non-incised midpoint										
1 (control)	0	0	3	9	7	21	15	45	23	70
2 (oil-water)	1	3	3	10	6	21	7	24	15	52
3 (oil-water)	1	3	9	24	14	38	14	38	17	46
4 (oil-water)	0	0	2	5	10	24	9	22	16	39
av. 2, 3, 4	-	3	-	13	-	28	-	27	-	44
5 (pressure reduction)	1	4	3	12	12	50	11	46	18	75

a- A- Not less than 1/2 inch penetration
B- Not less than 3/4 inch unless 100 per cent of sapwood is penetrated
C- Not less than 1 inch unless 100 per cent of sapwood is penetrated
D- Not less than 3/4 inch unless 100 per cent of sapwood is penetrated and 85 per cent of sapwood over 3/4 inch up to a maximum of 1 5/8 inch
E- Not less than 100 per cent penetration of sapwood

does not meet specifications A, B, and C; but a larger percentage does not meet specifications D and E. So few poles do not meet specifications A and B that the group's relative size would be greatly changed by the addition or exclusion of one pole. Therefore, except for the Charge 3 poles not meeting specification B at the midpoint, the percentage of poles not meeting specifications A and B gives no basis for comparison.

The average per cent of groundline and midpoint sapwood penetrated in poles grouped by sapwood depth is shown in Figure 5 and Table 11, and the per cent of each grouping showing complete sapwood penetration is listed in Table 11. Some penetrations are greater than 100 per cent as calculated by dividing the depth of penetration by sapwood depth and multiplying the result by 100. The average per cent of groundline sapwood treated in the oil-water charges, grouping them as one charge, is equal to or greater than that in the control. The inclusion of sapwood depth groups above 1 3/4 inches is not warranted because they represent so few poles. Each oil-water charge has a higher per cent of poles with complete groundline sapwood penetration in each group, and a higher average per cent of sapwood penetration.

The average per cent of midpoint sapwood penetrated in the oil-water charges, collectively, is greater in each

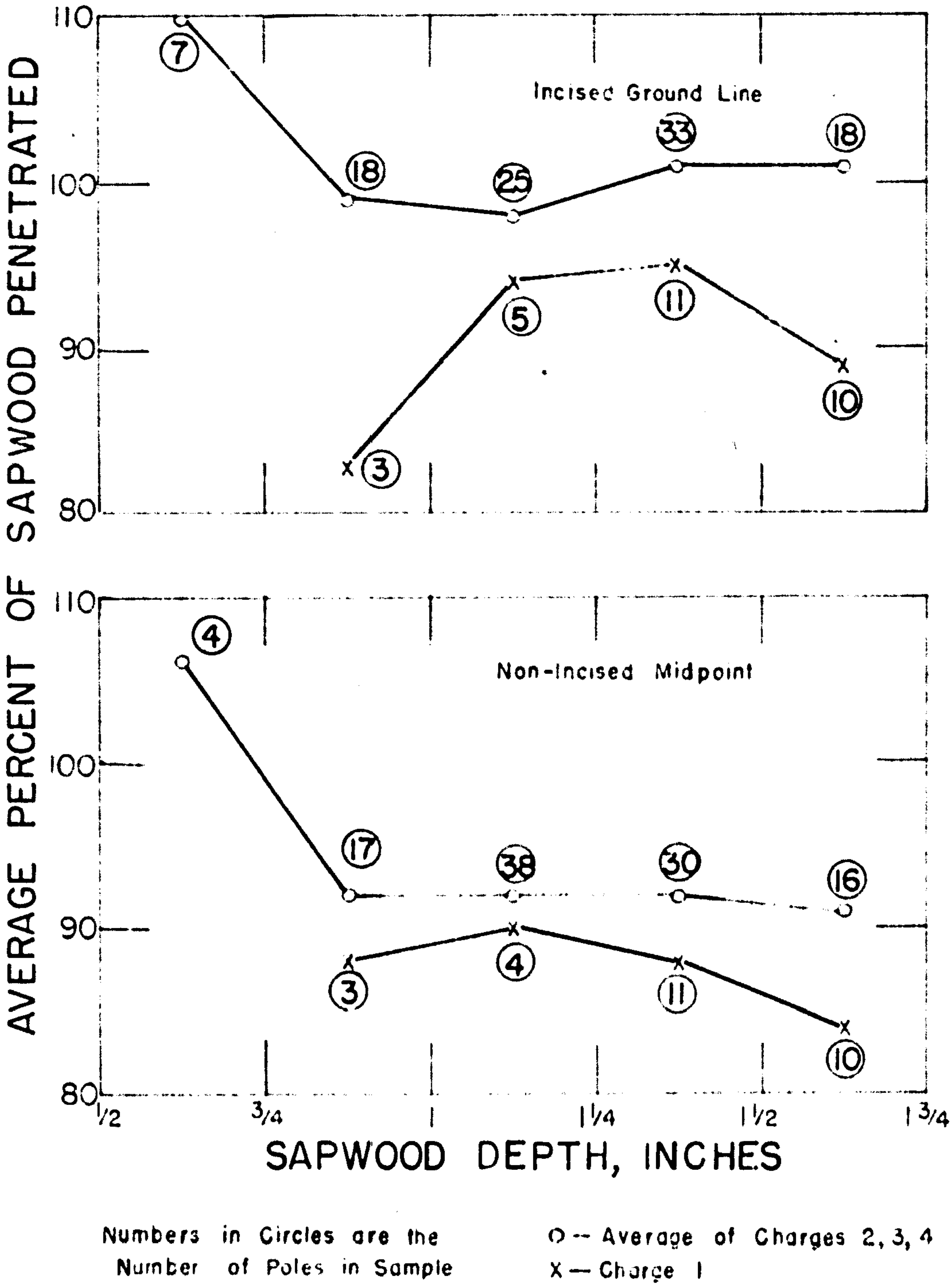

Figure 5. Penetrations in oil-water treated poles, grouped by sapwood depth

Table 11. Penetrations, in poles grouped by sapwood depths

Charge number	Sapwood depth limits measured from the surface inward, inches														
	1/2 to 3/4			3/4 to 1			1 to 1 1/4			1 1/4 to 1 1/2			1 1/2 to 1 3/4		
	A[a]	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Incised groundline															
1 (control)	0	-	-	3	83	33	5	94	40	11	95	55	10	89	30
2 (oil-water)	0	-	-	8	98	62	6	102	83	7	99	71	5	106	80
3 (oil-water)	5	106	100	8	99	75	6	96	83	10	103	100	10	98	83
4 (oil-water)	2	120	100	2	100	100	13	98	77	16	101	88	7	98	86
av. 2, 3, 4	-	110[b]	100	-	99	79	-	98	84	-	101	86	-	101	83
5 (pressure reduction)	1	100	100	2	96	50	6	91	33	5	95	80	5	91	0
Non-incised midpoint															
1 (control)	0	-	-	3	88	33	4	90	75	11	88	36	10	84	20
2 (oil-water)	1	100	100	4	89	50	8	105	75	8	84	25	6	82	33
3 (oil-water)	1	82	0	9	88	67	14	78	36	10	96	70	3	97	67
4 (oil-water)	2	131	100	4	100	75	16	92	61	12	95	50	7	93	57
av. 2, 3, 4	-	106	100	-	92	64	-	92	62	-	92	48	-	91	42
5 (pressure reduction)	0	-	-	4	82	25	10	81	30	6	80	17	2	62	0

a- A- Number of poles in group
B- Average per cent of ring type sapwood penetration
C- Per cent of poles in group with 100 per cent sapwood penetration

b- While average is 113 per cent, due to small number of poles an average value of 110 per cent is used sapwood group than in the control. In all but one sapwood depth group, a higher average percentage of the oil-water treatments resulted in complete sapwood penetration than of the control. But, comparing each oil-water charge with the control, only Charge 4 had a higher per cent of sapwood penetration in each group. On the whole, the oil-water treatments obtained only a little more midpoint penetration than the control.

Calculations of the midpoint and groundline penetrations of the oil-water charges to what would be obtained if they included the same percentage of poles with sapwood limits as the control are listed in Table 12. Poles having less than 3/4 inch sapwood depth or 1 3/4 inches or more were neglected because such penetrations did not occur in enough charges to promote accurate comparisons. Furthermore, the average sapwood depth of a group was assumed to fall half-way between its limits (that is, within limits of 1 to 1¼ inches the assumed average sapwood depth is 1 1/8 inches). The penetrations and average sapwood depths of the control charge were calculated for the poles, 28 at midpoint and 29 at groundline, that fell within the 3/4 to 1 3/4 inches limit. The average penetration was calculated for each experimental charge, assuming each to have the same percentage of poles in the sapwood depth groups as the control had. This renders the average groundline sapwood depths of the control and experimental charges

Table 12. Penetrations and sapwood depths, by calculation

Charge number	Number of poles in charge	Number of poles in sample	Calculated depth, inches: penetration	Calculated depth, inches: sapwood	% sapwood penetration	Increase[a], inches
			Incised groundline			
1[b] (control)	33	29	1.216	1.323	91.9	0.077
1 (control)	33	29	1.251	1.365	91.6	0.059
2 (oil-water)	29	26	1.396	1.365	102.3	0.215
3 (oil-water)	37	30	1.361	1.365	99.7	0.055
4 (oil-water)	41	38	1.355	1.365	99.3	0.059
5 (pressure reduction)	24	18	1.268	1.365	92.9	0.264
			Non-incised midpoint			
1[b] (control)	33	28	1.139	1.319	86.4	
1 (control)	33	28	1.192	1.374	86.8	
2 (oil-water)	29	26	1.181	1.374	86.0	
3 (oil-water)	37	36	1.306	1.374	95.0	
4 (oil-water)	41	39	1.296	1.374	94.2	
5 (pressure reduction)	24	22	1.004	1.374	73.0	

a- Increase in penetration in incised groundline over that in non-incised midpoint

b- Actual arithmetical average penetration and sapwood depths for sample equal, and also equalizes the average midpoint sapwood depths. Because poles containing deep sapwood were excluded, the average penetrations and sapwood depths of the control charge are generally lower in the extrapolations than in the total charge, and the reverse is true of the oil-water treatments. The average depth of extrapolated groundline penetration in each oil-water charge is greater than in the control; and the same is true, except for Charge 2, at the midpoint.

Retention. Calculations of the quantity of oil retained after treatment based on pole volume are generally and widely used for ease of calculation. Since the object of these experiments is to treat sapwood volume, retentions based on the latter are more significant, but do not account for sapwood depth and so those based on surface area also deserve consideration. As the relative consideration deserved by each type of retention is unknown, in general only sapwood volume retentions will be considered. Comparisons based on an average of the individual pole retentions, by weight gain and calculated volume, are sufficiently accurate.

The average retention of a charge can be controlled by the engineer, but the variation of pole retentions depends on chance grouping and treating methods. Variations are measured by the standard deviation, and approximately 67 per cent of the poles have retentions between the limits of the average retention plus and minus the standard deviation. For comparison the standard deviation is divided by the average retention to give the coefficient of variation, expressed in per cent. The number of poles with relatively high and low retentions increases with the coefficient of variation; thus increasing the number of poles that are apt not to meet specifications and that are apt to bleed.

The average retention of each oil-water charge, based on sapwood volume, is greater than that of the control, however the control had a retention only eight per cent below the average retention of all the oil-water charges and this difference is not great enough to invalidate direct comparison. The coefficient of variation of the retention when based on sapwood volume was about the same for all charges (see Table 8) and, when based on pole volume or surface area, was higher for the oil-water treatments than for the control. This probably has less significance than the variation based on sapwood volume. It is probable and to be expected that the coefficient of variation of retention of the oil-water treatments exceeds that of the conventional treatments. The easily treated poles in a charge absorb more oil than the others during the pressure period, and when immediately followed by a vacuum, as in conventional treatment, less oil is recovered from the refractory than the easily treated wood, and the retentions will differ less than if no oil had been removed, as the oil-water treatments show. Apparently that difference is not great enough to cause difficulty but, if necessary, modification of the oil-water schedules could probable reduce it.

Pentachlorophenol distribution. The average pentachlorophenol concentrations in the first and second quarter-inch and in the second and third half-inch of the control and oil-water treatments are shown in Table 9. The concentrations in each group of poles are in Appendix E. The pentachlorphenol concentration in the first half-inch of the control was greater at the non-incised midpoint than at the incised groundline; the reverse was true of the oil-water charges. The first half-inch of midpoint concentration was greater in the control than in the oil-water charges. The second and third half-inch of midpoint pentachlorphenol concentrations were about the same in all charges, but a large groundline concentration occurred in the oil-water charges.

The pentachlorophenol concentration gradient in the oil-water treated poles is flatter than that in the conventionally treated poles. That is, some of the preservative that would have been left near the surface by the conventional treatment was forced further into the wood by the oil-water treatment, but this action was not very pronounced.

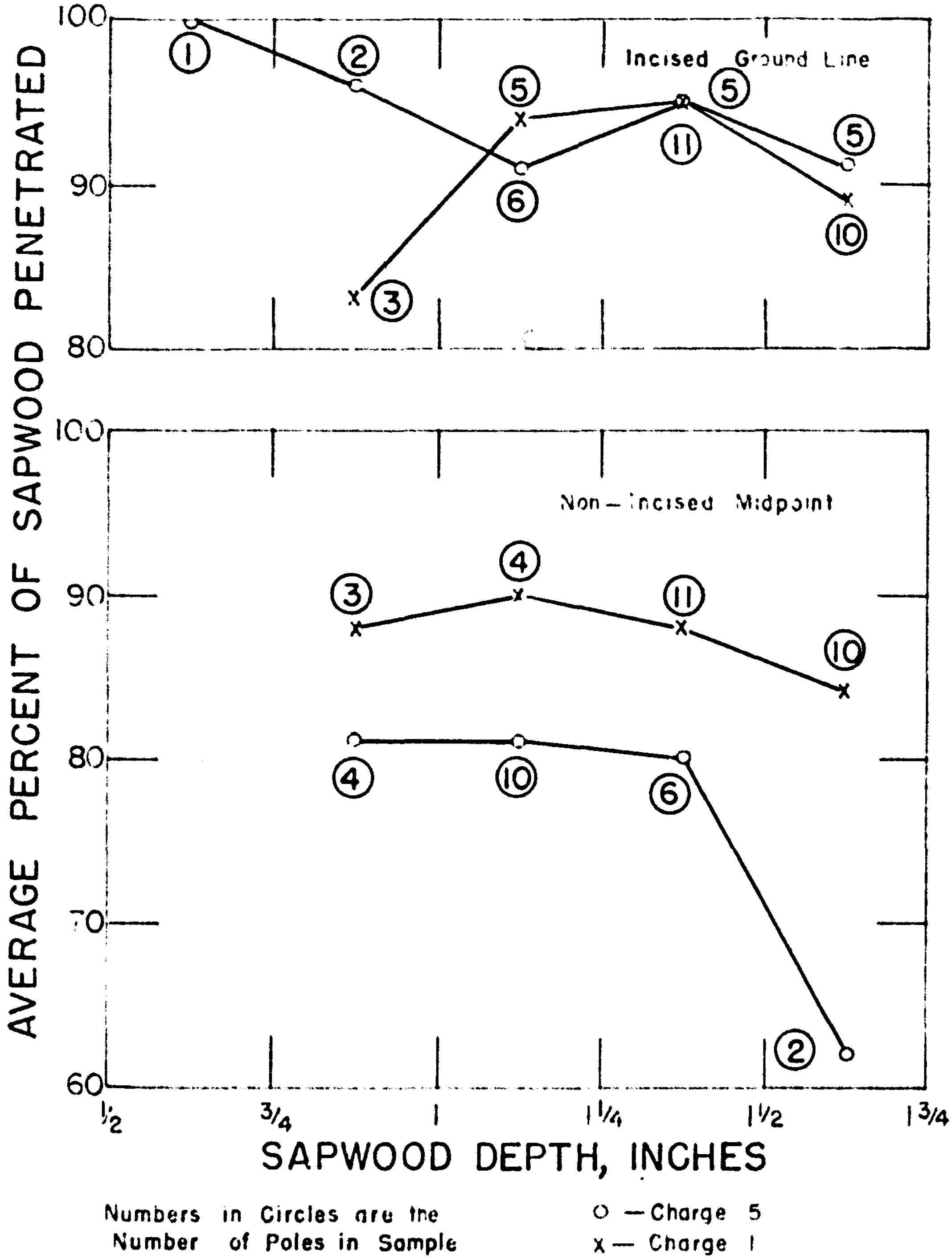

Figure 6. Penetrations in pressure reduction treated poles, grouped by sapwood depth

Pressure reduction treatment

The pressure reduction treatment, Charge 5, is compared for penetration, retention and pentachlorphenol content with the control charge.

Penetration. The average depth of penetration is lower in the pressure reduction charge than in the control (see Table 8), although their average sapwood depths are very similar. Methods of comparison are: the per cent of poles not meeting certain specifications; the average per cent of sapwood depth penetrated in poles grouped by sapwood depth; the estimated depth of penetration if the experimental charges and the control had the same average sapwood depth.

The number and per cent of poles in each charge that did not meet the penetration specifications, at the non-incised midpoint and the incised groundline, are listed in Table 10. The difference between the two charges, in percentage of poles meeting specifications, is small at the groundline, more pronounced at the midpoint, and generally, more control charge poles meet specifications.

The average per cent of groundline and midpoint sapwood penetrated in poles grouped by sapwood depth are shown in Figure 6 and Table 11, and the per cent of each group showing complete groundline and midpoint sapwood penetration are shown in Table 11. Each group, except the 1 to 1½ inch, in the reduced pressure charge had an average groundline sapwood penetration equal to or greater than the control. In general, a larger per cent of the poles in the reduced pressure groups had complete sapwood penetration than in the control.

In every group the average per cent of midpoint sapwood penetrated and the per cent of poles with complete sapwood penetration was greater for the control than the pressure reduction charge.

Calculations of the penetration of the pressure reduction charge to what would be obtained if it included the same percentage of poles with sapwood limits as the control are in Table 12. In the pressure reduction treatment groundline penetration is slightly greater and midpoint penetration is less than in the control.

Retention. The retention in the pressure reduction charge was 9.91 lb of oil per cu ft of pole based on the gauge readings and 4.82 lb of oil per cu ft of pole based on the weight gains of the poles. It is probable that such a discrepancy is due to an error in one of the measurements.

The oil retention can be estimated from the average pentachlorophenol contents in the charges when it is assumed that a direct relationship exists between the pentachlorophenol in the first half inch in the midpoint and the pounds of oil per cubic foot of pole. The pentachlorophenol concentrations in the first and second quarter-inch zones were multiplied by their respective fractional cross sectional areas and then added to give pounds of dry pentachlorphenol per cubic foot of pole; this was converted to pounds of oil per cubic foot of pole by multiplying by 20. The fractional cross section for each zone is found from an "average" pole for each charge; one that has the average diameter for the charge and pentachlorophenol concentrations in each zone equal to the average for the charge.

The average oil retention, based on the pentachlorophenol concentrations, for the first four charges is approximately 4.1 lb of oil per cu ft of pole and for the pressure reduction charge 2.95 lb of oil per cu ft of pole. This ratio, when multiplied by the average oil retention for the first four charges, based on the weight gain of the poles, gives an estimated oil retention for the pressure reduction charge of 4.9 lb of oil per cu ft of pole and 0.97 lb of oil per sq ft of surface. These values are very close to the retentions obtained from the weight gains of the poles of 4.8 lb of oil per cu ft of pole and 0.98 lb of oil per sq ft of surface area. Considering that the gauge readings are based on only two manonmeter readings, an error in one reading could easily cause this discrepancy.

The control charge, charge 1, absorbed 25 per cent more oil on a sapwood volume basis, or 34 per cent more oil on a pole volume basis, than the pressure reduction charge. This difference in oil absorptions is sufficient to invalidate any direct comparison of the penetrations. The numerical relationship between penetration and retention is unknown; however, the control charge would have been expected to have a shallower groundline penetration than the pressure reduction charge, had its retention been only 4.82 lb of oil per cu ft of pole, and the same might be true of the midpoint penetrations.

The coefficient of variation of the retention based on the sapwood volume of the reduced pressure charge was approximately the same as that of the control; however, the variations in the retentions based on pole volume and on surface area were greater than those of the control. The variation of retention in the reduced pressure treatment is probably greater than that of the control but less than that of the water treatment and does not appear to be high enough to cause any difficulty.

<u>Pentachlorophenol distribution</u>. The average pentachlorophenol concentrations in the first and second quarter-inch and in the second and third half-inch of the pressure reduction treatment are shown in Table 9. The concentrations in each group of poles are in Appendix E. In each

zone the average concentrations are less than those in the control charge, which is due to the lower oil retention. However, in each zone the pentachlorophenol content is materially higher in the incised groundline than in the non-incised midpoint.

The pentachlorophenol concentration gradient in the reduced pressure charge is steeper than that of the control and oil-water charges, which may be due to the relatively lower oil retention in the reduced pressure charge.

Limitations of comparison

The primary limitation in any comparison of this nature is the extent to which these results are indicative of those to be obtained from a larger number of trials. As the sample size increases, its results approach the average result of treating an infinite number of poles, so the extreme variability of wood may invalidate conclusions based on a small number of poles. Consequently, the results of each treatment are assumed to be representative of it, and the comparisons are assumed to err as the results deviate from its norm.

A second limitation is the extent to which the numerical values actually represent the variable measured. Probably the calculated average penetration in a pole closely represents the actual average penetration. The weight gain of a pole, however, may not actually represent the net oil retention because the pole continually loses and gains both oil and water throughout the treatment as well as when out of the cylinder after the initial weighing and before the final vacuum.

The weight gain of a pole then equals the net oil retention only if the amounts of water injected into and removed from the pole between the weighing periods are equal, and if the pole loses no oil after being removed from the cylinder. The latter probably accounts for only a small fraction of the gain or loss, and the laboratory oil-water treatments indicate but a slight net water gain. Therefore, the weight gain of a pole is assumed to closely represent the net oil retention under these experimental conditions, as verified by the retention results of Charges 1, 3, and 4 in Table 7. During or at the end of the water period, the highly permeable poles (those with abnormally high retentions) in Charge 2 possibly expelled oil, which would not be measured by the gauge.

Since net oil retention measured by weight gain refers to the whole pole, if retention is increased in the incised part it must decrease in the non-incised part, with corresponding changes in penetration. The average length of the poles treated was approximately 40 feet, 6 feet of which were incised. Since the end with the larger diameter was incised, and from it there is longitudinal penetration, the average effective incised area was about 20 per cent of the pole. If the net retention of a pole is 6.00 lb per cu ft, and the net retention of the incised area is 50 per cent higher than the non-incised area, the net retention (excluding end absorption, for simplification) will be 5.56 lb per cu ft of non-incised pole and 8.19 lb per cu ft of effective incised pole. If the net absorption of the incised portion were only 25 per cent more than the non-incised portion, the retentions would be 7.14 and 5.7 lb per cu ft, respectively.

The oil-water and pressure reduction treatments tend to give a higher ratio of incised to non-incised retention than the conventional treatment because, in the latter, a vacuum applied immediately after the pressure period causes greater oil recovery per unit of incised than non-incised wood. This principle also applies to end absorption, so the percentage of net retention due to radial absorption is probably higher in the conventional charge than in the experimental charges. This limitation probably is not very important in this comparison.

Discussion of Results

The results of the commercial experiments show that deeper groundline penetrations occurred in the oil-water and pressure reduction charges than in the control charge, and that deeper midpoint penetrations occurred in the oil-water charges than in the control. Heartwood penetration, though not generally recognized in commercial practice, has definite significance in a comparison of treatments. Its occurrence in all the oil-water treatments, but not in the control, apparently indicates that the former method has a greater potential for deep penetration than the conventional method.

Of the oil-water treatments Charge 4, with water at 150 psi for 0.5 hour and then at 50 psi for 5.5 hours, appears to have slightly better penetration than Charge 3, with water pressure slowly reduced from 90 to 0 psi in 6.0 hours. Charge 2 is not sufficiently representative to be included in the comparison because its actual treating schedule greatly deviated from that desired. Although their differences in retention do not promote a reliable comparison, there is indication that oil-water treatment may give better penetrations than pressure reduction treatment in poles requiring very short pressure periods such as the 0.15 to 1.3 hours at 150 psi required by Charges

2 and 4 for a 6 pound retention. Because the laboratory work in which pole sections required 3 to 4 hours at 150 psi for the same retention was the basis for the commercial scale treating schedules, all but one of the charges absorbed more oil than anticipated. The effect of permeability upon the relationship between retention, penetration, and treating schedule is unknown, but had the commercial scale experiments treated wood as refractory as that upon which the treatments were developed they would probably show even more improvement over the conventional method of treatment.

To insure long service life as much preservative as possible should be absorbed in the incised groundline area; however, the conventional treatment leaves less in that area than in the midpoint, though the reverse is true of the experimental treatments. The penetration increase due to incising is much more pronounced in the experimental charges than in the conventional charge, as shown in Table 12. In the control charge this increase was only 0.06 inch out of a possible 0.17, while in Charges 2 and 5 it was 0.22 and 0.26 inch out of a possible 0.22 and 0.32 inch, respectively. In Charges 3 and 4 such deep midpoint penetration occurred that incising would have had little benefit. Nevertheless, it is quite evident that the experimental treatments utilize incising much more than does the conventional treatment.

The conventional treating schedule, used for the control charge, is based on years of experience in treating thousands of poles. The oil-water and reduced pressure reduction treatments have had little development; thus their results show only the potentiality of, rather than the ultimate in these types of treatment, and as more commercial experience in their application is gained, they may be expected to show even better results.

CONCLUSIONS

The following conclusions of the effects of the oil-water and the pressure reduction treatment of coast-type Douglas fir can be made.

1. The oil-water method of treatment gives deeper penetrations in both the incised groundline and the non-incised midpoint than the conventional (Lowry) type of treatment.
2. The pressure reduction treatment gives deeper penetration in the incised groundline than the conventional (Lowry) type of treatment.
3. The increase in penetration due to incising is more pronounced in the oil-water and pressure reduction treatments than in the conventional (Lowry) type of treatment.
4. The ratio of the pentachlorophenol content in the incised wood to that in the non-incised wood is larger for the oil-water and pressure reduction treatments than for the conventional (Lowry) type of treatment.

The above conclusions are based on treating results of highly permeable Douglas fir poles and the advantages of the oil-water and the pressure reduction treatments should be greater in the treatment of refractory Douglas fir poles.

The oil-water treatment appears preferable to the pressure reduction treatment but, because the data from the latter on a commercial scale were insufficient, no valid comparison can be made. It is believed that the improvements resulting from the oil-water and pressure reduction treatments warrant their slight additional cost, but this cannot be definitely concluded until the service lives of the poles are known.

While a longer cylinder time was needed for the oil-water than the pressure reduction treatment in the commercial scale testing, in practice the reverse would probably be true. Up to five hours can be cut from the duration of the oil-water treatment by eliminating the preheating in oil and the flash steaming, reducing the water period, using 150 psi air, and other operational procedures.

Continued commercial scale testing of the oil-water and pressure reduction treatments on a semi-production basis is recommended.

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APPENDICES

APPENDIX A

Method of Sealing the Ends of Pole Sections

The following method was used to seal the ends of poles to prevent end penetration during the treating process. About a day after the wood was cut to the desired length, each end was dipped for about 10 seconds in a resorcinol-formaldehyde solution and then heated for 1 minute with infra-red heat lamps. The resorcinol-formaldehyde solution was prepared immediately before application by mixing 95 ml of a 40 per cent water solution of formaldehyde with 155 ml of a solution consisting of 5 pounds of resorcinol, 5 pounds of water, and 0.1 pound of NaOH. A day later the process was duplicated except that a 60-second dip was used and that, after heating, the ends were painted with sodium silicate (specific gravity 1.4). The following day the ends were painted with Tygon paint (TP-12, black, U. S. Stoneware Co.).

This produced a seal which allowed only 1 inch end penetration. However, the Tygon coating will deteriorate at temperatures above 200°F.

APPENDIX B

Method of Pentachlorophenol Analysis

The pentachlorophenol content in the pressure reduction charge, charge 5, were determined by the Dow Chemical Company, Midland, Michigan, using the Bell Telephone Co. method KS-4629, Section 2.17, Issue 2, November 13, 1950, "Determination of Chloride in Miscellaneous Organic Materials." The pentachlorophenol contents in the first four charges were determined by using a modification of the American Wood Preservers' Association method A5-51 "standare Methods for Analysis of Oil-borne Preservatives." This method is described below.

Three grams of potassium nitrate, ground to pass a 30 mesh screen, were mixed with 27 grams of calcium hydroxide and 10 grams of the mixture were placed in a 100 ml Armco iron crucible. The crucible was tapped, the wood was added, 20 more grams of calcium hydroxide mixture were added, and the crucible was tapped again. The crucible was heated for 35 minutes, starting at low heat and ending at the full heat of a No. 4 Meker burner.

After cooling, the contents of the crucible were placed in a 400 ml beaker and covered with a watch glass. About

60 ml of distilled water and the liquid from three rinsings of the crucible with dilute nitric acid were added to the beaker. The beaker was placed in a stream of cold water and 100 ml of 50 per cent concentrated nitric acid were added. Then the solution was stirred until the reaction ceased.

After cooling, 10 ml of 0.1 N silver nitrate were added, the solution was boiled for 3 minutes, cooled, vacuum-filtered through Watman No. 40 filter paper into a 500 ml filtering flask, and the filter paper was washed five times with distilled water. The filtered solution was transferred to the 400 ml beaker and titrated with approximately 0.1 N ammonium thiocyanate after adding 5 ml of Volhard indicator. Near the endpoint the filtering flask was rinsed by pouring the solution from the beaker into the filtering flask and then back into the beaker. It was then titrated to the first permanent pink endpoint.

The above procedure, without wood, was also used in determining the reagent blank.

The following calculation gives the pounds of dry pentachlorophenol per cubic foot of wood assayed, when the wood cores are obtained with a 0.20 inch diameter increment borer:

$$\frac{(10 - \text{ml } 0.1 \text{ N ammonium thiocyanate} - \text{reagent blank})}{\text{linear inches of } 0.20 \text{ in. dia. core}} \times 0.646.$$

APPENDIX C

Oil and Water Distributions

Table 13. Oil and water distributions, by extraction, in Douglas fir pole sections treated by the oil-water process

Section number	Increment of depth, inches	Retention, lb oil per cu ft	% oil by wt	Moisture, %	Condition of surface	Days after treatment
96	0 - 1/4	15.4	51.0	11.4	wet	6
	1/4- 1/2	13.2	43.8	12.1		
	1/2- 3/4	7.2	24.2	11.3		
	3/4-1	3.4	11.2	13.0		
	1 -1 1/2	1.1	3.5	13.5		
96	0 - 1/4	16.1	53.3	7.6	wet	8
	1/4- 1/2	7.0	23.3	10.6		
	1/2- 3/4	2.9	9.8	11.7		
	3/4-1	4.0	13.3	10.0		
	1 -1 1/2	0.4	1.2	13.6		
97	0 - 1/4	11.7	44.4	9.2	wet	3
	1/4- 1/2	4.6	17.4	11.4		
	1/2- 3/4	1.5	5.5	14.3		
	3/4-1	0.7	2.8	15.3		
	1 -1 1/2	0.8	3.1	18.3		
	1 1/2-2	0.2	0.6	19.5		
97	0 - 1/4	11.9	44.9	7.9	wet	5
	1/4- 1/2	2.8	10.7	11.4		
	1/2- 3/4	2.0	7.6	13.2		
	3/4- 1	1.3	4.9	14.6		
	1 -1 1/2	1.6	5.9	17.0		
	1 1/2-2	0.5	1.9	18.1		
99	0 - 1/4	9.3	38.8	14.5	dry	6
	1/4- 1/2	9.8	40.9	40.0		
	1/2- 3/4	10.0	41.5	69.7		
	3/4-1	8.6	36.0	72.6		
	1 -1 1/2	7.2	30.2	62.0		
	1 1/2-2	0.3	1.4	37.1		
101	0 - 1/4	11.1	28.1	14.7	dry	1
	1/4- 1/2	6.4	16.3	38.9		
	1/2- 3/4	0.0	0.0	20.9		
	3/4-1	0.0	0.0	18.0		

Table 13. (Continued)

Section number	Increment of depth, inches	Retention, lb oil per cu ft	% oil by wt	Moisture, %	Condition of surface	Days after treatment
4-3	0 - 1/4	17.3	67.6	13.3	wet	1
	1/4- 1/2	13.8	53.8	12.1		
	1/2- 3/4	10.8	42.1	11.6		
	3/4-1	12.6	49.3	11.6		
	1 -1 1/4	11.2	43.7	10.0		
	1 1/4-1 1/2	4.3	16.8	8.7		
4-4	0 - 1/4	17.1	66.5	13.3	wet	1
	1/4- 1/2	15.0	58.6	12.0		
	1/2- 3/4	9.4	36.7	11.8		
	3/4-1	7.4	29.0	12.5		
	1 -1 1/4	4.6	17.8	12.3		
	1 1/4-1 1/2	1.9	7.4	10.9		
4-6	0 - 1/4	14.4	55.8	24.1	wet	1
	1/4- 1/2	11.1	43.0	26.8		
	1/2- 3/4	11.7	45.4	24.8		
	3/4-1	11.7	45.4	21.8		
	1 -1 1/4	10.0	39.0	20.3		
	1 1/4-1 1/2	4.8	18.7	15.0		
4-7	0 - 1/4	13.8	53.1	13.9	wet	1
	1/4- 1/2	10.2	39.1	14.0		
	1/2- 3/4	5.9	22.8	13.5		
	3/4-1	7.0	26.9	13.5		
	1 -1 1/4	6.7	25.6	12.4		
	1 1/4-1 1/2	1.7	6.6	12.1		
4-9	0 - 1/4	15.8	60.6	12.4	wet	1
	1/4- 1/2	9.8	37.4	11.8		
	1/2- 3/4	7.2	27.6	13.2		
	3/4-1	6.5	24.7	10.0		
	1 -1 1/4	5.3	20.2	15.8		
	1 1/4-1 1/2	1.5	15.6	10.0		
4-16	0 - 1/4	9.8	38.4	10.0	wet	1
	1/4- 1/2	5.9	23.1	14.2		
	1/2- 3/4	5.3	20.6	14.6		
	3/4-1	3.5	13.4	12.3		
	1 -1 1/4	2.9	11.5	11.2		
	1 1/4-1 1/2	0.6	2.2	13.6		

Table 13. (Continued)

Section number	Increment of depth, inches	Retention, lb oil per cu ft	% oil by wt	Moisture, %	Condition of surface	Days after treatment
4-18	0 - 1/4	11.8	46.2	12.5	wet	1
	1/4- 1/2	7.9	30.8	19.2		
	1/2- 3/4	6.6	25.7	15.9		
	3/4-1	6.1	23.8	17.0		
	1 -1 1/4	4.6	18.1	17.7		
	1 1/4-1 1/2	2.0	8.0	16.7		
4-20	0 - 1/4	13.6	52.6	7.1	wet	1
	1/4- 1/2	9.0	34.8	10.3		
	1/2- 3/4	7.8	26.2	11.0		
	3/4-1	6.3	24.3	11.2		
	1 -1 1/4	5.3	20.4	15.1		
	1 1/4-1 1/2	2.7	10.3	13.2		
4-21	0 - 1/4	13.9	53.6	7.4	wet	1
	1/4- 1/2	7.0	27.7	13.0		
	1/2- 3/4	6.1	23.7	11.4		
	3/4-1	6.6	25.6	12.7		
	1 -1 1/4	7.2	28.0	12.4		
	1 1/4-1 1/2	2.4	9.4	9.3		

Table 14. Oil and water distributions, by extraction, in Douglas fir pole sections treated by the pressure reduction process

Section number	Increment of depth, inches	Retention, lb oil per cu ft	% oil by wt	Moisture, %	Condition of surface	Days after treatment
86	0 - 1/2	8.9	27.0	6.0	wet	9
	1/2-1	4.6	14.0	11.0		
	1 -1 1/2	3.3	10.0	15.0		
94	0 - 1/4	9.9	34.8	7.7	wet	2
	1/4- 1/2	10.3	36.0	11.2		
	1/2- 3/4	9.4	32.9	11.8		
	3/4-1	6.8	23.9	12.4		
	1 -1 1/4	3.4	11.9	13.7		
	1 1/4-1 3/4	2.7	9.5	13.1		
	1 3/4-2 1/4	1.4	4.8	13.8		
94	0 - 1/4	11.4	40.1	5.7	wet	5
	1/4- 1/2	4.7	20.1	7.9		
	1/2- 3/4	4.2	14.6	7.8		
	3/4-1	3.2	11.5	9.7		
	1 -1 1/4	2.3	7.9	10.8		
	1 1/4-2	1.0	3.4	10.2		
94	0 - 1/4	9.2	32.4	5.2	wet	9
	1/4- 1/2	4.4	15.3	8.0		
	1/2- 3/4	2.9	10.1	8.7		
	3/4-1	2.3	7.9	10.0		
	1 -1 1/2	1.7	6.1	10.6		
	1 1/2-2	0.7	2.5	11.6		
95	0 - 1/4	10.8	26.4	6.2	wet	3
	1/4- 1/2	6.2	20.8	7.6		
	1/2- 3/4	3.8	12.7	8.5		
	3/4-1	3.5	11.8	9.2		
	1 -1 1/2	2.5	8.4	11.1		
	1 1/2-2	3.4	11.4	9.2		
95	0 - 1/4	8.1	27.1	7.2	wet	5
	1/4- 1/2	3.5	11.6	9.8		
	1/2- 3/4	2.9	9.9	9.9		
	3/4-1	2.9	9.6	11.1		
	1 -1 1/2	2.2	7.4	12.5		
	1 1/2-2	2.9	9.8	13.2		

Table 14. (Continued)

Section number	Increment of depth, inches	Retention, lb oil per cu ft	% oil by wt	Moisture, %	Condition of surface	Days after treatment
4-5	0 - 1/4	17.2	66.0	6.6	wet	1
	1/4- 1/2	10.7	41.0	8.7		
	1/2- 3/4	7.4	28.6	9.0		
	3/4-1	4.2	15.9	11.0		
	1 -1 1/4	2.5	9.5	9.3		
	1 1/4-1 1/2	1.2	4.4	10.0		
4-8	0 - 1/4	19.3	74.0	6.2	wet	1
	1/4- 1/2	13.3	51.0	7.1		
	1/2- 3/4	9.8	37.4	8.5		
	3/4-1	10.3	39.6	9.3		
	1 -1 1/4	7.4	28.3	9.6		
	1 1/4-1 1/2	5.0	19.3	10.1		
4-17	0 - 1/4	13.1	51.2	3.8	wet	1
	1/4- 1/2	11.0	42.7	5.5		
	1/2- 3/4	7.6	29.5	6.5		
	3/4-1	6.1	23.9	8.4		
	1 -1 1/4	5.3	20.7	9.7		
	1 1/4-1 1/2	2.4	9.4	9.8		

APPENDIX D

Retentions and Penetrations in Douglas Fir Poles

TABLE 15. Retentions and penetrations in coast-type Douglas fir poles in Charge 1, treated according to the usual practice of the Franklin Park plant of the Joslyn Mfg. and Supply Co. with a 5 percent solution of pentachlorophenol.

Pole No.	Class & Length	Av. Dia. inches	Moisture, %[a]	Lb wt gain per cu. ft. pole	Lb wt gain per cu. ft. sap.	Lb wt gain per sq. ft. surface	Midpoint penetration Inches comp	Midpoint penetration Inches ring	Midpoint penetration sap.	Midpoint penetration % of sap comp	Midpoint penetration % of sap ring	Groundline penetration Inches comp	Groundline penetration Inches ring	Groundline penetration sap.	Groundline penetration % of sap comp	Groundline penetration % of sap ring
1	5-35	8.91	17	6.5	11.6	1.22	0.75	1.00	1.25	60	80	1.00	1.19	1.25	80	95
2	5-35	9.39	16	5.4	8.7	1.07	0.94	1.12	1.50	62	75	1.44	1.44	1.62	88	88
3	5-35	8.83	15	6.1	10.4	1.15	0.94	1.19	1.38	68	86	1.06	1.25	1.25	86	100
4	5-35	8.04	18	7.0	10.0	1.21	1.12	1.50	2.00	56	75	1.12	1.44	1.81	62	79
5	1-35	11.94	15	7.2	16.1	1.81	1.00	1.38	1.62	62	85	1.12	1.31	1.50	75	88
6	4-40	11.34	22	5.5	10.4	1.17	0.88	1.06	1.50	58	71	1.12	1.25	1.56	72	80
7	2-40	10.94	18	7.4	24.7	1.68	1.12	1.31	1.31	86	100	1.38	1.38	1.38	100	100
8	1-40	13.05	15	6.1	13.6	1.67	1.31	1.50	1.56	84	96	1.25	1.62	1.62	77	100
9	5-30	8.40	19	6.7	10.8	1.18	0.69	0.75	1.50	46	50	0.75	0.94	1.56	48	60
10	4-35	9.55	17	8.2	13.7	1.66	1.06	1.62	1.62	66	100	1.25	1.62	1.62	74	100
11	5-35	8.36	16	6.4	10.0	1.40	0.88	1.25	1.31	67	95	1.31	1.31	1.31	100	100
12	5-35	8.59	15	6.7	13.3	1.22	0.44	1.00	1.31	33	76	0.56	0.88	1.06	53	82
13	4-40	10.66	19	5.0	11.8	1.13	0.69	0.94	1.44	48	65	1.06	1.31	1.50	71	88
14	5-35	9.03	16	5.6	10.1	1.08	0.81	0.94	1.25	65	75	1.00	1.06	1.31	76	81
15	5-35	8.91	16	8.1	15.5	1.51	1.12	1.31	1.31	86	100	1.12	1.19	1.19	95	100
16	4-35	9.51	17	7.9	15.3	1.57	1.44	1.44	1.44	100	100	1.25	1.25	1.25	100	100
17	5-35	9.59	17	6.8	11.2	1.37	0.88	1.19	1.56	56	90	1.19	1.38	1.50	79	92
18	5-35	9.15	20	2.6	7.5	0.50	0.38	0.62	1.06	35	59	0.31	0.50	0.88	36	57
19	5-35	8.56	17	5.4	12.2	0.98	0.56	0.69	0.75	75	92	0.88	0.88	0.93	93	93
20	5-35	9.27	16	5.7	11.0	1.12	0.69	1.12	1.12	61	100	1.00	1.12	1.25	80	90
21	5-35	8.79	16	6.5	8.7	1.20	0.69	0.88	1.88	33	47	1.00	1.62	1.69	55	90
22	5-35	8.75	18	9.2	14.4	1.73	1.75	1.88	2.00	88	94	1.31	1.81	2.38	55	76
23	5-35	8.59	18	6.6	8.2	1.19	0.81	1.06	2.25	36	47	1.06	1.25	2.25	47	56
24	5-35	9.63	16	7.0	13.3	1.41	0.81	1.19	1.25	65	95	0.94	1.12	1.31	71	86
25	5-35	8.99	17	6.0	9.6	1.13	1.06	1.44	1.50	72	96	0.81	1.38	1.44	56	96
26	5-35	9.23	18	6.7	12.1	1.30	0.75	1.25	1.25	60	100	1.44	1.44	1.44	100	100
27	5-35	8.52	18	10.6	16.5	1.92	1.69	1.69	1.69	100	100	1.69	1.69	1.69	100	100
28	5-35	8.67	14	6.1	12.2	1.12	0.69	0.69	0.94	73	73	0.88	0.94	1.00	88	94
29	5-35	9.03	18	4.9	9.3	0.94	0.94	1.19	1.19	79	100	1.00	1.00	1.00	100	100
30	5-35	8.79	17	7.5	11.1	1.41	0.88	1.31	2.12	41	62	1.50	1.81	1.94	77	94
31	5-35	9.23	16	6.8	15.4	1.31	0.94	1.06	1.06	88	100	1.00	1.00	1.06	94	94
32	5-40	9.19	17	5.7	10.6	1.09	0.94	1.19	1.50	62	79	1.06	1.25	1.25	85	100
33	4-45	11.66	16	5.7	19.0	1.40	0.69	0.75	0.75	92	100	0.88	0.94	0.94	93	100
Average		9.43	17	6.4	12.2	1.30	0.92	1.17	1.43	64[b]	82[b]	1.08	1.26	1.42	76[b]	89[b]

a- determined by electric moisture meter with 5/16 inch prongs
b- calculated by dividing the average penetration by the average sapwood depth

TABLE 16. Retentions and penetrations in coast-type Douglas fir poles in charge 2, treated by the water process with a 5 percent solution of pentachlorophenol.

Pole No.	Class & Length	Av. Dia. inches	Moisture, % [a]	Lb wt gain per cu ft pole	Lb wt gain per cu ft sap.	Lb wt gain per sq ft surface	Midpoint penetration Inches comp	Midpoint penetration Inches ring	Midpoint penetration sap.	Midpoint penetration % of sap. comp	Midpoint penetration % of sap. ring	Groundline penetration Inches comp	Groundline penetration Inches ring	Groundline penetration sap.	Groundline penetration % of sap. comp	Groundline penetration % of sap. ring
34	4-50	11.34	22	2.7	5.5	0.65	1.19	1.25	1.31	90	95	1.44	1.44	1.44	100	100
35	4-45	10.66	17	8.2	21.4	1.83	1.06	1.50	1.19	89	126	1.00	1.25	1.12	89	111
36	5-40	10.26	19	6.6	10.6	1.41	1.25	1.38	1.38	91	100	1.00	1.12	1.12	89	100
37	5-35	8.95	18	11.8	15.9	2.26	1.12	1.44	2.19	51	59	1.25	2.00	2.56	49	78
38	5-35	8.28	18	8.9	15.0	1.57	0.50	0.75	1.12	44	67	1.06	1.31	1.31	81	100
39	5-35	8.75	16	10.4	15.2	1.91	0.75	1.12	1.12	67	100	1.31	1.44	1.44	91	100
40	5-40	9.35	16	5.5	16.7	1.09	0.38	0.81	0.75	50	108	0.62	1.00	0.94	67	107
41	4-45	10.11	16	5.0	15.2	1.34	0.62	0.75	0.75	83	100	0.75	1.06	0.75	100	142
42	1-50	14.01	20	3.4	10.6	1.01	0.62	0.88	1.44	44	61	0.56	0.69	1.00	56	69
43	4-45	11.30	22	3.6	11.5	0.85	0.50	0.69	0.69	73	100	0.69	0.75	0.75	92	100
44	4-45	11.20	20	5.2	13.6	1.21	1.00	1.19	1.06	94	112	1.06	1.19	1.19	89	100
45	5-40	9.15	17	8.0	14.3	1.55	1.31	1.31	1.31	100	100	1.38	1.50	1.50	92	100
46	5-35	9.11	16	10.5	14.7	2.01	0.69	1.50	1.62	42	92	1.31	1.69	1.69	78	100
47	5-40	9.87	16	5.7	12.9	1.17	1.06	1.19	1.19	90	100	1.00	1.19	1.06	94	112
48	4-45	11.10	24[b]	5.0	9.3	1.17	0.50	1.06	1.62	31	65	0.50	0.81	1.75	29	46
49	1-50	14.12	22	3.5	4.8	1.04	0.62	1.12	1.25	50	90	1.06	1.38	1.38	77	100
50	4-45	10.26	18	9.3	16.1	1.93	1.12	1.56	1.75	64	89	1.12	1.44	1.56	72	92
51	5-40	9.35	17	5.3	10.7	1.04	1.00	1.31	1.44	70	91	1.12	1.19	1.25	90	95
52	5-35	8.67	18	14.9	19.8	2.78	1.69	1.69	1.69	100	100	1.94	2.62	1.94	100	135
53	5-35	9.39	18	11.24	15.4	2.22	0.75	1.50	1.62	46	92	1.19	1.81	1.50	79	121
175	5-35	8.12	22	11.6	17.4	1.99	0.94	1.31	1.44	65	91	0.94	1.25	1.31	72	95
55	5-35	8.67	18	9.6	18.0	1.77	1.06	1.56	1.06	100	147	1.31	1.31	1.31	100	100
56	5-35	9.23	20	3.4	6.5	0.66	0.25	0.44	0.94	27	47	0.50	0.69	0.81	62	85
57	5-35	9.07	22	5.6	15.5	1.06	0.69	0.88	1.00	89	88	1.00	1.12	1.12	89	100
58	5-35	9.03	19	4.2	6.9	0.80	0.44	0.69	1.50	29	46	0.50	0.69	0.88	57	78
59	5-35	9.59	20	6.8	10.7	1.41	0.62	1.62	1.62	38	100	0.69	1.81	1.56	46	116
60	5-35	8.79	18	8.4	24.7	1.55	0.62	0.81	0.81	77	100	0.75	0.88	0.88	86	100
61	5-35	9.35	18	10.5	17.9	2.05	0.31	0.50	1.25	25	40	0.50	0.94	1.06	47	88
62	5-35	8.63	22	5.4	15.3	1.01	0.62	1.00	1.00	62	100	0.81	0.94	0.94	87	100
Average		9.85	19	7.2	13.9	1.46	0.80	1.13	1.28	62[c]	88[c]	0.98	1.26	1.28	77[c]	98[c]

a- determined by electrical moisture meter with 5/16 inch prongs
b- moisture content is greater than 24 percent
c- calculated by dividing the average penetration by the average sapwood depth.

TABLE 17. Retentions and penetrations in coast-type Douglas fir poles in charge 3, treated by the water process with a 5 percent solution of pentachlorophenol.

Pole No.	Class & Length	Av. Dia. inches	Moisture, %[a]	Lb wt gain per cu ft pole	Lb wt gain per cu ft sap.	Lb wt gain per sq ft surface	Midpoint penetration Inches comp	Midpoint penetration Inches ring	Midpoint penetration % of sap. sap.	Midpoint penetration % of sap. comp	Midpoint penetration % of sap. ring	Groundline penetration Inches comp	Groundline penetration Inches ring	Groundline penetration % of sap sap.	Groundline penetration % of sap comp	Groundline penetration % of sap ring
63	5-35	9.07	22	3.4	12.0	0.65	0.62	0.62	1.00	62	62	0.69	0.69	0.69	100	100
64	5-35	8.36	24[a]	5.6	9.5	1.06	0.88	1.12	1.25	70	90	1.25	1.25	1.50	83	83
65	5-35	9.35	20	3.8	10.2	0.74	0.62	0.81	0.81	77	100	0.69	0.94	0.88	69	107
66	5-35	8.71	21	4.5	9.5	0.83	0.44	0.62	1.31	33	48	0.62	0.75	0.75	63	100
67	7-35	8.18	17	8.8	15.5	1.49	0.88	1.19	1.19	74	100	1.31	1.69	1.62	81	104
68	5-40	9.71	20	6.6	13.3	1.34	0.94	1.38	1.38	68	100	1.31	1.31	1.31	100	100
69	4-45	11.42	21	7.6	16.0	1.77	0.75	1.00	1.25	60	80	0.94	1.25	1.25	75	100
70	4-50	10.82	20	7.1	11.9	1.62	0.94	1.56	1.31	72	119	1.56	1.56	1.56	100	100
71	1-45	13.45	14	9.0	23.9	2.53	0.94	0.94	0.94	100	100	0.88	0.94	0.94	93	100
72	4-45	11.30	18	5.5	11.8	1.30	0.75	1.19	1.19	63	100	1.00	1.25	1.25	80	100
73	4-45	11.30	18	7.3	18.4	1.72	1.12	1.31	1.25	90	105	1.44	1.56	1.44	100	109
74	2-50	11.26	16	6.7	12.4	1.61	1.00	1.25	1.25	80	100	0.88	1.31	1.31	67	100
75	4-45	10.99	18	4.7	9.8	1.07	0.88	0.94	0.94	93	100	1.00	1.19	1.19	84	100
76	4-45	11.02	18	6.1	13.2	1.42	1.38	1.44	1.38	100	104	1.44	1.56	1.44	100	109
77	5-40	10.34	22	4.7	9.0	1.02	0.75	0.88	1.12	67	78	0.75	0.94	0.94	80	100
78	5-40	9.91	17	8.2	16.3	1.70	1.06	1.19	1.06	100	112	1.19	1.38	1.25	95	110
79	5-45	10.11	15	8.8	20.6	1.86	1.06	1.19	1.19	89	100	1.06	1.25	1.12	94	111
80	5-45	10.26	18	5.9	11.6	1.28	1.00	1.19	1.12	89	105	1.19	1.31	1.25	95	105
81	5-40	8.89	18	10.4	18.9	1.98	1.38	1.44	1.44	96	100	1.38	1.38	1.38	100	100
82	5-35	9.75	20	4.3	10.1	0.88	0.50	0.50	0.94	53	53	1.06	1.06	1.06	100	100
83	5-35	9.15	22	4.4	9.0	0.85	0.69	0.69	0.94	73	73	1.12	1.12	1.12	100	100
84	5-35	9.95	18	2.1	5.9	0.44	0.25	0.56	0.69	36	82	0.56	0.56	0.56	100	100
85	5-35	8.95	24[b]	4.6	12.0	0.86	0.62	0.88	0.88	71	100	1.69	1.69	1.69	100	100
86	5-35	8.99	24[b]	5.0	13.6	0.95	0.69	0.88	0.88	79	100	0.75	0.88	0.88	86	100
87	5-35	9.07	20	5.7	11.4	1.09	0.69	0.75	1.00	69	75	0.88	1.00	1.00	88	100
88	5-35	9.89	20	2.5	11.8	0.53	0.50	0.50	1.06	47	47	0.44	0.50	0.50	88	100
89	5-35	8.95	24[b]	5.9	9.4	1.15	0.69	0.69	1.12	61	61	1.25	1.62	2.00	62	81
90	5-35	8.75	24[b]	4.1	7.5	0.75	0.31	0.38	1.06	29	35	0.44	0.69	0.62	70	110
91	5-35	8.67	18	10.6	18.1	1.98	1.50	1.69	1.62	92	104	1.44	1.44	1.44	100	100
92	5-35	10.26	23	3.0	5.7	0.66	0.50	0.56	0.88	57	64	0.69	0.81	0.68	100	118
93	5-35	8.79	21	4.3	9.8	0.82	0.56	0.75	0.75	75	100	0.56	0.69	0.75	75	92
94	5-35	8.52	18	9.0	16.8	1.63	0.50	0.94	1.06	47	88	1.25	1.69	1.81	69	93
95	5-35	8.97	24[b]	4.0	8.0	0.74	0.50	0.88	1.19	42	74	0.56	0.69	0.75	75	92
96	5-35	9.03	18	3.6	5.8	0.70	1.00	1.44	1.62	62	88	1.38	1.69	1.69	82	100
97	5-35	8.56	20	4.9	13.7	0.88	0.56	0.62	1.00	56	62	0.75	0.75	0.75	100	100
98	1-45	12.26	18	5.7	12.5	1.49	1.06	1.56	1.38	77	114	0.69	0.75	1.19	58	63
99	4-50	10.82	20	8.9	13.5	2.05	1.56	1.69	1.69	93	100	1.56	1.56	1.56	100	100
Average		9.83	20	5.9	12.4	1.23	0.81	1.01	1.14	71[c]	89[c]	1.02	1.15	1.16	88[c]	99[c]

a- determined by electrical moisture meter with 5/16 inch prongs
b- moisture content is greater than 24 percent
c- calculated by dividing the average penetration by the average sapwood depth

TABLE 18. Retentions and penetrations in coast-type Douglas fir poles in charge 4, treated by the water process with a 5 percent solution of pentachlorophenol.

Pole No.	Class & Length	Av Dia. inches	Moisture, %[a]	Lb wt gain per cu ft: pole	Lb wt gain per cu ft: sap.	Lb wt gain per sq ft surface	Midpoint penetration, Inches: comp	Midpoint penetration, Inches: ring	Midpoint penetration, Inches: sap.	Midpoint penetration, % of sap.: comp	Midpoint penetration, % of sap.: ring	Groundline penetration, Inches: comp	Groundline penetration, Inches: ring	Groundline penetration, Inches: sap.	Groundline penetration, % of sap: comp	Groundline penetration, % of sap: ring
100	4-45	11.42	23	3.5	8.0	0.83	0.56	0.75	1.00	56	75	0.62	0.75	1.00	62	75
101	5-40	10.19	19	8.5	14.0	1.81	1.25	1.38	1.38	91	100	1.38	1.56	1.44	96	109
102	7-35	7.04	17	10.0	18.2	1.50	0.81	1.12	1.25	65	90	1.00	1.12	1.12	89	100
103	7-35	7.40	17	12.4	22.6	1.93	1.19	1.19	1.25	95	95	1.31	1.31	1.31	100	100
104	7-35	7.48	16	9.6	13.8	1.50	1.12	1.19	1.12	100	105	1.50	1.50	1.50	100	100
105	5-40	10.26	17	7.3	13.6	1.56	0.69	1.00	1.25	55	80	1.25	1.25	1.25	100	100
106	4-45	12.02	20	5.6	10.3	1.41	1.12	1.19	1.12	100	105	1.38	1.69	1.38	100	123
109	7-35	7.08	16	10.6	15.0	1.59	0.81	1.12	1.12	72	100	1.19	1.25	1.19	100	105
110	7-35	7.52	17	11.4	17.4	1.78	0.81	1.12	1.06	76	106	1.25	1.38	1.25	100	110
111	7-35	7.48	16	11.4	20.0	1.79	1.12	1.12	1.12	100	100	1.06	1.06	1.06	100	100
112	7-35	7.80	18	7.3	11.6	1.19	1.06	1.19	1.06	100	112	1.00	1.25	1.06	94	118
113	5-40	8.56	18	13.1	19.0	2.39	1.56	1.56	1.56	100	100	1.50	1.50	1.50	100	100
114	5-45	9.99	18	6.4	18.0	1.36	1.19	1.25	1.25	95	100	1.44	1.44	1.44	100	100
115	5-40	8.83	24	5.7	9.4	1.06	1.31	1.31	1.38	96	96	0.75	1.06	1.44	52	74
116	7-35	7.52	17	12.5	17.6	1.99	1.25	1.38	1.25	100	110	1.19	1.44	1.19	100	121
117	7-35	7.40	22	7.8	13.3	1.21	0.62	1.00	0.69	91	145	1.69	1.75	1.69	100	104
118	7-35	7.88	20	6.6	13.7	1.09	0.94	0.94	1.06	88	88	1.06	1.06	1.06	100	100
119	4-45	9.55	20	8.7	17.0	1.75	1.25	1.38	1.25	100	110	1.19	1.38	1.31	90	105
120	4-40	10.42	18	7.6	14.6	1.67	1.38	1.38	1.50	92	92	1.06	1.44	1.38	77	105
121	4-40	9.63	18	9.4	14.5	1.91	1.00	1.56	1.62	62	96	1.44	1.62	1.81	79	90
122	7-35	7.60	18	8.2	14.4	1.48	0.69	0.75	1.00	69	75	1.38	1.50	1.38	100	109
124	4-40	9.67	19	7.8	15.5	1.59	1.12	1.69	1.31	86	129	1.06	1.38	1.12	94	122
125	5-40	10.03	20	8.8	12.4	1.85	1.19	1.50	1.50	79	100	1.69	1.69	1.69	100	100
126	5-40	9.47	18	4.9	10.8	0.98	0.69	0.94	1.56	44	60	0.88	1.19	1.50	58	79
127	5-40	9.83	20	8.3	17.0	1.71	1.19	1.19	1.19	100	100	1.31	1.31	1.31	100	100
131	7-35	7.76	16	9.7	15.2	1.59	1.19	1.44	1.44	83	100	1.25	1.38	1.25	100	110
133	7-35	7.80	18	6.6	12.3	1.09	0.56	0.88	1.12	50	78	0.62	0.81	0.81	77	100
134	4-40	10.86	20	6.6	12.7	1.53	0.88	0.94	1.38	64	79	1.56	1.56	1.56	100	100
135	4-40	9.83	20	5.0	12.9	1.03	0.56	0.81	0.69	82	118	0.69	0.81	0.81	85	100
136	7-35	8.04	17	8.6	12.4	1.66	1.38	1.56	1.50	92	104	1.44	1.62	1.44	100	113
137	7-35	8.08	16	5.7	12.6	0.96	0.62	0.81	0.88	71	93	1.06	1.06	1.31	81	81
138	7-35	7.80	18	8.3	12.6	1.37	0.88	0.94	0.88	100	107	1.19	1.31	1.25	95	105
139	7-35	7.85	18	8.0	14.0	1.32	1.00	1.00	1.00	100	100	1.00	1.19	1.00	100	119
140	5-40	10.23	20	9.6	14.8	2.07	1.50	1.50	1.50	100	100	1.69	1.69	1.69	100	100
141	5-45	10.11	24[b]	5.0	10.4	1.06	0.94	0.94	0.94	100	100	1.00	1.00	1.00	100	100
142	5-35	8.83	24	4.9	9.8	0.90	0.69	0.81	1.00	69	81	0.56	0.69	0.56	100	122
143	5-30	8.83	20	5.2	12.2	0.95	0.56	0.75	0.75	75	100	0.69	0.81	0.69	100	118
144	5-30	8.83	24	1.6	3.3	0.29	1.12	1.12	1.12	100	100	0.31	0.38	1.19	26	32
145	5-30	8.24	20	7.2	11.7	1.25	1.12	1.25	1.19	95	105	1.19	1.19	1.19	100	100
146	5-30	8.20	22	4.3	6.6	0.75	0.38	0.69	1.38	27	50	0.81	0.88	1.31	62	67
147	5-35	9.43	21	3.5	7.8	0.69	0.44	0.56	1.00	44	56	0.50	0.81	1.00	50	81
Average		8.85	19	7.7	13.5	1.40	0.97	1.13	1.18	84[c]	96[c]	1.12	1.24	1.25	90[c]	99[c]

a- determined by electrical moisture meter with 5/16 inch prongs
b- moisture content is greater than 24 percent
c- calculated by dividing the average penetration by the average sapwood depth

TABLE 19. Retentions and penetrations in coast-type Douglas fir poles in charge 5, treated by the reduced pressure process with a 5 percent solution of pentachlorophenol.

Pole No.	Class & Length	Av. dia. inches	Moisture, %[a]	Lb wt gain per cu ft pole	cu ft sap	sq ft surface	Midpoint penetration Inches comp	Inches ring	Inches sap.	% of sap. comp	% of sap. ring	Groundline penetration Inches comp	Inches ring	Inches sap.	% of sap comp	% of sap ring
148	4-35	9.47	18	5.6	9.8	1.12	0.88	0.94	1.12	78	83	1.44	1.56	1.62	88	96
149	5-35	8.79	20	4.3	7.3	0.79	0.44	0.62	1.38	32	45	0.62	0.81	0.81	77	100
150	5-40	10.03	17	3.4	10.6	0.71	0.81	0.81	0.94	87	87	0.88	0.88	0.94	93	93
151	4-45	11.18	15	8.1	20.8	1.89	0.88	1.00	1.25	70	80	0.50	1.00	1.00	50	100
152	4-50	10.66	16	5.2	9.3	1.17	1.06	1.12	1.12	94	100	0.88	1.56	1.69	52	93
153	4-50	10.58	17	5.1	8.8	1.16	0.62	1.88	1.88	33	100	1.25	1.69	1.94	64	87
154	5-45	9.55	24	6.6	12.7	1.32	0.88	1.00	1.00	88	100	0.94	1.19	1.19	79	100
155	4-50	10.90	17	4.2	8.5	0.95	0.81	1.25	1.31	62	95	0.94	1.44	1.50	62	96
156	4-55	11.78	22	3.7	9.2	0.91	0.56	0.69	1.00	56	69	0.69	1.00	1.06	65	94
157	4-50	11.62	19	3.9	7.4	0.95	0.38	1.44	1.69	22	85	1.06	1.44	1.50	71	96
158	5-45	9.81	18	3.8	10.8	0.94	0.25	0.38	1.00	25	38	0.56	0.56	1.75	32	32
159	5-45	10.09	19	4.8	10.5	1.02	0.56	0.88	1.19	47	74	0.88	1.06	1.44	61	74
160	4-45	10.74	17	5.8	10.1	1.32	1.19	1.38	1.38	86	100	0.88	1.19	1.56	56	76
161	4-50	10.66	18	5.0	7.0	1.15	0.50	1.75	2.12	24	82	0.69	1.06	2.12	32	50
162	4-45	10.15	19	5.4	9.4	1.15	0.44	0.75	1.50	29	50	0.56	1.19	1.94	29	61
163	5-40	9.59	20	3.6	8.2	0.73	0.56	0.69	0.88	64	78	0.81	0.88	1.00	81	88
164	5-35	9.17	18	4.8	8.7	0.89	0.38	0.75	1.12	33	67	0.50	0.81	1.06	47	76
165	5-35	8.99	17	3.2	7.5	0.59	0.50	0.75	0.75	67	100	0.56	0.69	0.69	82	100
166	5-35	8.59	17	6.3	10.2	1.14	0.56	1.12	1.12	60	100	1.06	1.38	1.38	77	100
167	5-35	8.63	18	6.2	9.4	1.12	0.56	1.12	1.25	50	90	0.88	1.31	1.31	67	100
168	5-35	8.44	16	4.3	11.4	0.78	0.50	0.56	0.94	53	60	0.81	1.00	1.12	72	89
169	5-40	9.39	18	6.6	11.4	1.30	0.62	1.00	1.38	45	73	0.69	1.50	1.75	39	86
170	4-45	10.86	19	1.6	4.8	0.37	0.50	0.94	1.06	47	88	1.25	1.31	1.31	95	100
171	4-50	12.45	16	4.2	10.1	1.11	0.56	0.94	1.06	53	88	0.81	1.31	1.31	62	100
Average		10.09	18	4.8	9.7	0.98	0.62	0.99	1.23	50[b]	81[b]	0.84	1.16	1.37	61[b]	85[b]

a- determined by electrical moisture meter with 5/16 inch prongs
b- calculated by dividing the average penetration by the average sapwood depth

APPENDIX E

Pentachlorophenol Concentrations in Douglas Fir Poles

Table 20. Concentrations of dry pentachlorophenol in groups of Douglas fir poles

Numbers of poles in group	Lb[a] of dry pentachlorophenol per cu ft of sample[b] occurring in the zones[c]							
	non-incised midpoint				incised groundline			
	0-¼"	¼-½"	½-1"	1-1½"	0-¼"	¼-½"	½-1"	1-1½"
Charge 1								
1, 2, 3, 4, 5	1.230	1.023	0.599	0.284	1.121	0.961	0.729	0.524
6, 7, 8, 9,10	1.209	1.059	0.768	0.594	1.204	1.085	0.778	0.368
11,12,13,14,15	1.318	0.796	0.544	0.368	1.147	0.904	0.640	0.503
16,17,18,19,20	1.199	1.085	0.422	0.445	0.951	0.910	0.562	0.364
21,22,23,24,25	1.194	0.992	0.612	0.330	1.168	1.023	0.543	0.213
26,27,28,29,30	1.080	0.904	0.428	0.492	1.111	1.033	0.797	0.688
31,32,33	1.189	1.016	0.614	0.762	1.111	0.956	0.575	0.458
Charge 2								
34,35,36,37,38,39	1.326	1.098	0.646	0.517	1.223	1.068	0.728	0.576
40,41,42,43,44	1.039	0.806	0.472	0.388	1.163	0.915	0.754	—
45,46,47,48	1.105	0.808	0.599	0.620	1.182	0.982	0.672	0.747
49,50,51,52,53	0.966	0.863	0.626	0.443	1.147	0.966	0.668	0.506
55,56,57,58,175	1.065	0.641	0.459	0.336	0.961	0.832	0.523	0.517
59,60,61,62	1.066	0.988	0.663	0.207	1.105	1.040	0.520	0.217
Charge 3								
65,66,67,68,69	1.220	0.749	0.326	0.191	1.323	1.018	0.591	0.261
70,71,72,73,74	1.499	1.018	0.662	0.689	1.509	1.199	0.749	0.489
75,76,77,78,79	1.220	1.059	0.630	0.399	1.483	1.168	0.853	0.620
80,81,84,85,86	1.090	0.734	0.505	0.504	1.059	0.918	0.648	0.756
87,88,90,91,92	1.163	0.919	0.491	0.439	0.842	0.506	0.540	0.565
63,64,82,83,89,96	1.365	0.762	0.435	0.226	1.456	1.060	0.612	0.189
93,94,95,97,98,99	1.370	0.840	0.695	0.701	1.064	0.827	0.499	0.491

a- Weighted average, calculated by dividing total pounds of dry pentachlorophenol in zone by total volume of wood in zone analyzed

b- No untreated sapwood nor any heartwood was analyzed

c- Measured from surface of poles inward

Table 20. (Continued)

Numbers of poles in group	Lb[a] of dry pentachlorophenol per cu ft of sample[b] occurring in the zones[c]							
	non-incised midpoint				incised groundline			
	0-¼"	¼-½"	½-1"	1-1½"	0-¼"	¼-½"	½-1"	1-1½"
Charge 4								
119,120,121,122,124	1.256	1.147	0.927	0.650	1.209	1.096	0.775	0.370
125,131,133,135,136	1.147	1.018	0.520	0.212	1.173	1.028	0.620	0.322
137,138,139,142,143	1.276	0.832	0.354	0.078	1.121	0.884	0.533	0.827
144,145,146,147,141	0.961	0.786	0.533	0.620	1.028	0.729	0.557	0.620
100,101,105,106,113,114	1.137	1.008	0.622	0.521	1.025	1.068	0.890	0.573
115,126,127,134,140	1.266	1.049	0.581	0.505	1.282	1.245	0.843	0.656
102,103,104,109,110	1.406	1.023	0.604	0.327	1.411	1.173	0.677	0.413
111,112,116,117,118	1.328	1.085	0.783	0.672	1.380	1.137	0.716	0.716
Charge 5								
148,149,150,151,152	1.080	0.574	0.220	0.074	1.178	0.853	0.318	0.297
153,154,155,156,157	0.858	0.419	0.119	0.048	1.075	1.018	0.413	0.171
158,159,160,161,162	0.951	0.615	0.267	0.123	0.992	0.775	0.514	0.199
163,164,165,166,167	0.894	0.460	0.231	0.284	1.070	0.687	0.276	0.071
168,169,170,171	1.163	0.872	0.369	0.103	1.176	1.124	0.481	0.126

a- Weighted average, calculated by dividing total pounds of dry pentachlorophenol in zone by total volume of wood in zone analyzed

b- No untreated sapwood nor any heartwood was analyzed

c- Measured from the surface of poles inward